HEAT

SCIENCE SERVICE

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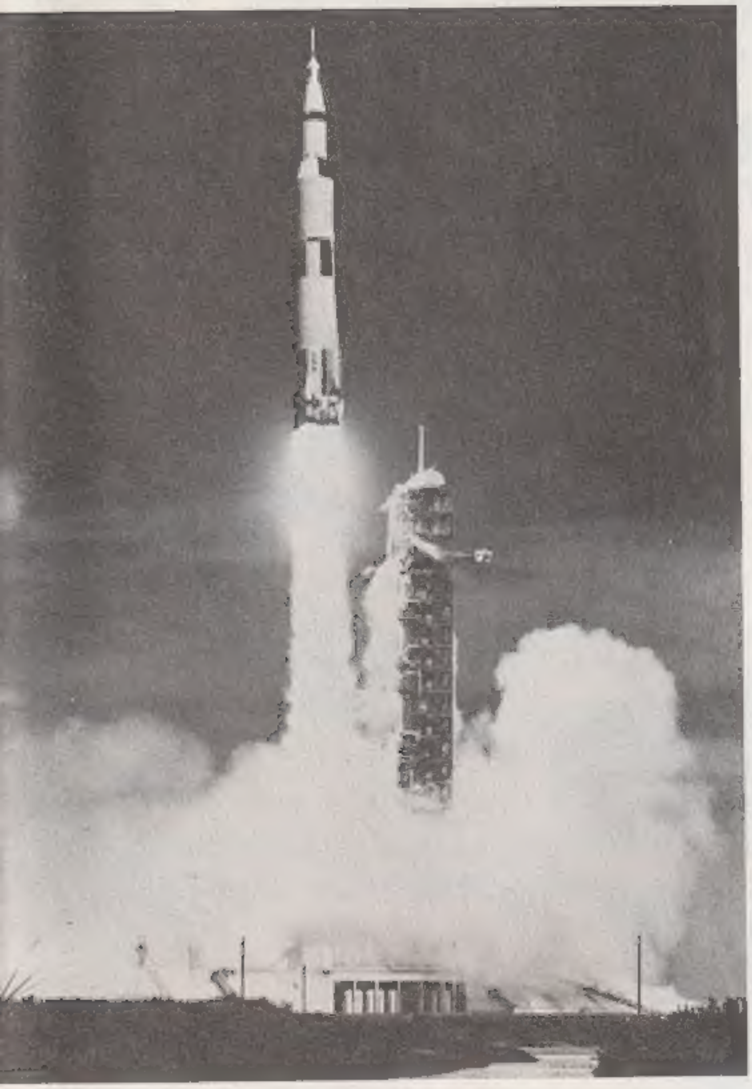


Imagine the heat generated by the 7½ million pounds of thrust from this Saturn V rocket as it lifted the Apollo 15 crew off the Kennedy Space Center pad on the first leg of their journey to the moon.

How Man Discovered Fire

MAN DID NOT INVENT FIRE—he discovered it. When volcanoes erupted and released white-hot molten lava, or when lightning struck dry trees, prehistoric man observed the phenomenon of fire. Man then began to use fire, possibly keeping a nature-made fire burning by feeding it twigs and timber. But he still had to learn the art of starting a fire by himself, by striking sparks with stone or flint, or by energetically rubbing together two pieces of dry wood.


Lacano

Traces of the use of fire have turned up in a cave of Peking man, an early primitive being that lived 250,000 years ago. Our own species, *homo sapiens,* learned from their ancestors how to use fire for cooking. The bones of animals which our ancestors killed and cooked can be found at many of their ancient camp sites.

Fire breaks down tough flesh into food which the human stomach can more easily digest. Thus man was freed from the burdensome task of chewing and digesting raw meat. He could use his extra energy to hunt and multiply his species.

Then some ancient man discovered how to make pottery. A piece of pottery is much more than dried clay. To produce true ceramic pottery, the clay must be baked at the intense temperature of 1,500° Fahrenheit. The heating drives out the water contained in the aluminum silicate or other minerals that make up the clay, and fuses the minerals into hard, brittle pottery. Afterwards, the clay will no longer dissolve in water, al-

1. LIGHTNING STRIKES

When lightning strikes dry timber, an uncontrolled forest fire may start. The result: intense heat.

though it may remain porous. A well-made piece of pottery can remain intact in the ground for centuries, and is often one of the most important clues available to archaeologists.

Pottery can be hardened in an open campfire, but for better results, a kiln must be used. The early potter learned that he could concentrate and conserve the heat of his fire by making it in a hole or trench. The next step was a closed kiln, with the fire underneath and the pottery above. The pottery of most simple cultures was fired at about 500° centigrade. More advanced cultures did a more thorough job, firing their earthenware at 900° C

Then man began to use fire to transform ores into metals—first bronze and then iron. The manipulation of intense heat also led to the making of glass.

Antoine Lavoisier conducts experiments with the flow of heat.

For 1,500 years the necessary heat for these processes was provided simply by burning wood or charcoal. But new sources of fuel, such as coal and oil, brought hotter flames to man's furnaces. He learned how to use metals and fuels to make engines which convert heat into mechanical energy. The heat engines freed him from his dependence upon his own muscular energy and that of animals, and with the development of the heat engine came an understanding of the nature of heat itself.

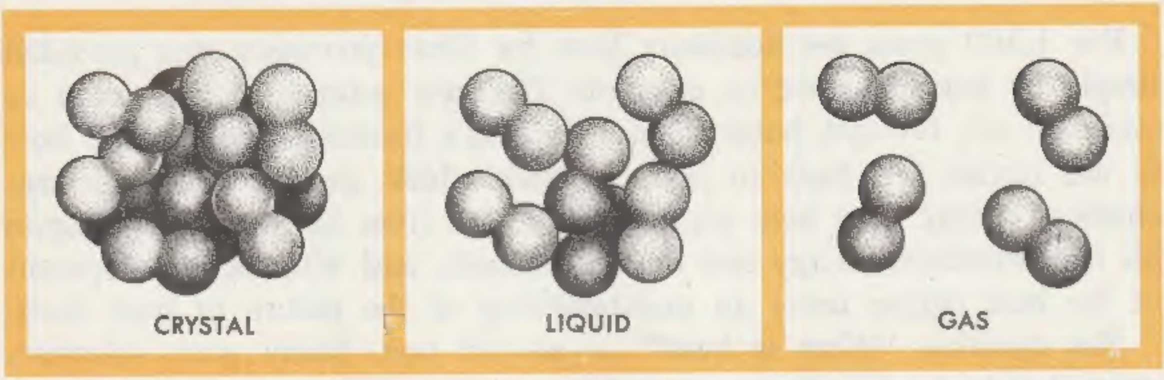
The question "What is heat?" is an old one. Many great scientists attempted to explain the nature of heat, without having gained a thorough understanding of it. Only in recent years have scientists found a satisfactory explanation for the concept of *hot* and *cold*.

The father of modern chemistry, Antoine Lavoisier, and the mathematician, Pierre Laplace, studied the flow of heat and found that it could be measured and that it obeyed certain laws. Nevertheless, they still believed that heat was a fluid, called "caloric", which weighed nothing, and was invisible, tasteless and odourless. According to this erroneous concept, hot bodies contained more caloric than cold ones, and the transfer of heat from one body to another was the result of a flow of caloric. This idea is still present in our language when we speak of the "flow of heat".

This explanation failed to satisfy Count Rumford, who was born Benjamin Thompson in Woburn, Massachusetts (1753–1814), but later spent much of his life in Europe. Rumford was a self-taught amateur scientist who became interested in the subject of heat while supervising the job of boring cannon for the Bavarian army. He noticed that the cannon became very hot during the boring process. So hot, in fact, that the water used to cool the cannon continually boiled away. Rumford wanted to know: Where was all that caloric coming from?

Rumford experimented and came to the conclusion that heat was not a special fluid, but was rather a form of energy. Mechanical energy went into turning the boring tools and reappeared as heat—*heat and mechanical motion were one and the same.*

This is in accord with the law of conservation of energy, first suggested by the German physicist Robert Mayer, and firmly established by Helmholz, which says that energy cannot be manufactured or destroyed, but can only be changed from one form to another. Mechanical energy can be transformed into heat, as in the case of friction, and heat can be transformed into mechanical energy, as in the case of a steam engine.



IN A SOLID THE MOLECULES VIBRATE IN CLOSE CONTACT

IN A LIQUID THE MOLECULES VIBRATE MORE VIOLENTLY

IN A GAS THE MOLECULES MOVE FREELY

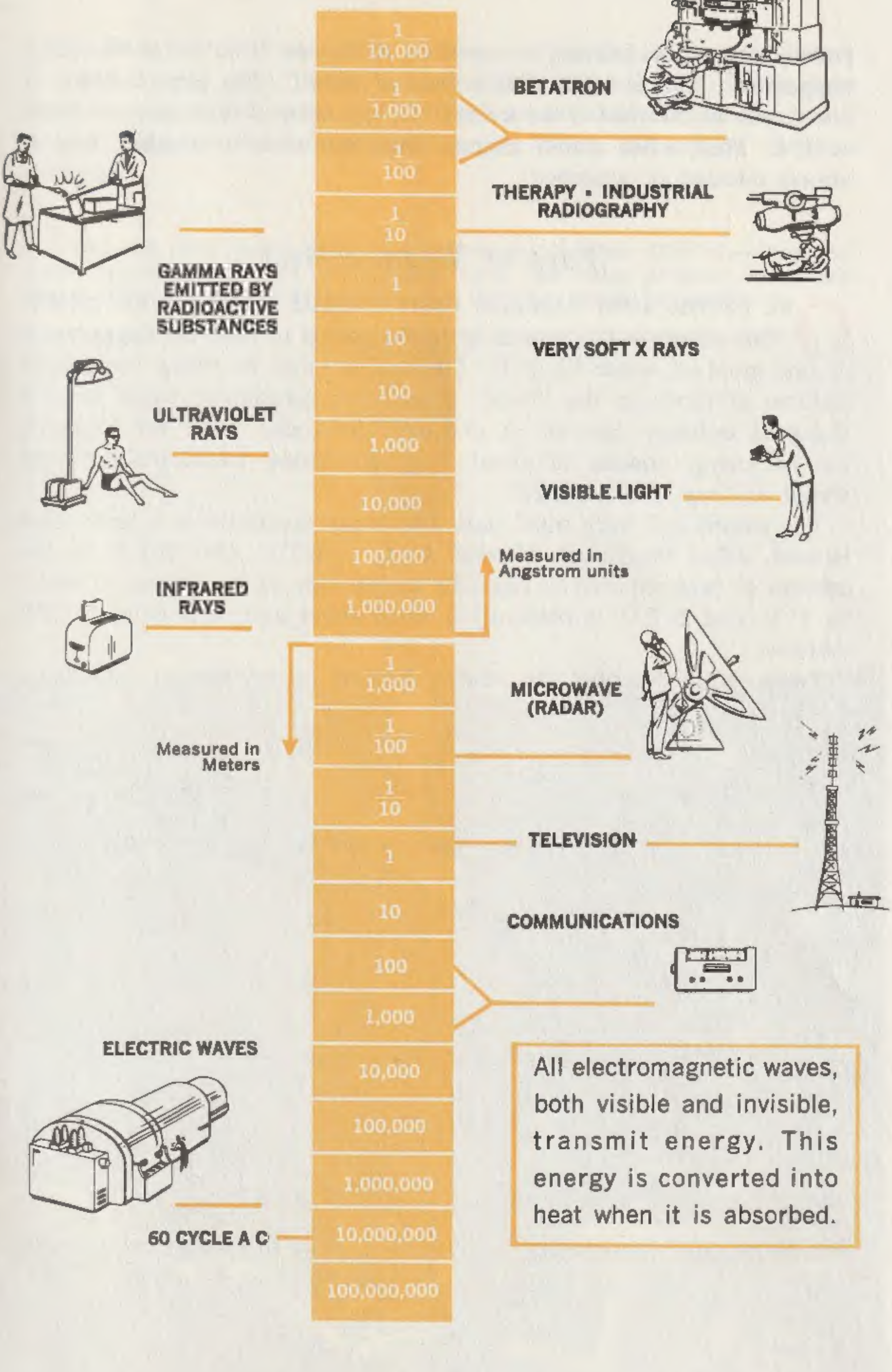
The erroneous concept of caloric was not demolished until the British physicist, James Prescott Joule, performed a very precise experiment. He rotated paddles in a tub of water and found that the heat gained by the water was exactly equal to the mechanical work used to move the paddles. This discovery proved that heat and mechanical work were equivalent forms of energy.

But the nature of heat is not completely explained merely by noting its equivalence to energy. In the early 1800s scientists became fairly sure that matter was composed of tiny particles called atoms, and small groups of these atoms, called molecules. They supposed that if you rubbed something, the motion of these tiny particles would speed up. In fact, the energy of their motion is what we call heat.

The speed of the moving molecules is related to temperature. The faster they move, the higher their temperature. If a solid becomes hot enough, its molecules vibrate so fast that they loosen their connections with neighbouring molecules. When that happens, the solid turns into a liquid. At still higher temperatures, the molecules move about even more violently, so that they are completely torn apart from each other. At that point the liquid becomes a gas. This view of heat as the motion of molecules is called the *kinetic* theory of heat.

The three forms in which things can exist—solid, liquid and gas—are called "the three states of matter". In changing from one state to another, heat is either absorbed or given off. For example, 970 B.T.U. of heat is needed to convert a pound of water at its boiling point to a pound of steam at the same temperature. This heat is called "latent heat of vaporization". On the other hand, 144 B.T.U. must be removed from a

The Electromagnetic Spectrum



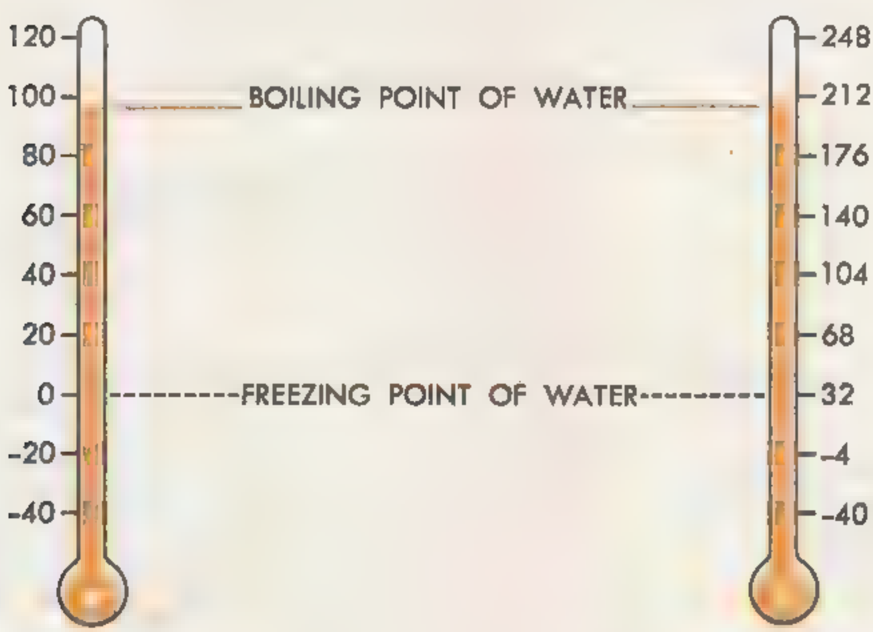
pound of water at freezing temperature to convert it to ice at the same temperature. This is called "latent heat of fusion". The same amount of heat has to be returned to the ice at 0° C. to convert it once more to water at 0° C. Thus, when matter changes from one state to another, heat is always released or absorbed.

Ways to Measure Heat

ONE OF THE MOST FAMILIAR UNITS assigned to heat is the calorie. One calorie is the amount of heat required to raise the temperature of one gram of water by 1° C. The calorie used in rating the energy content of foods is the "large calorie" or kilocalorie, equal to one thousand ordinary calories. A chocolate ice-cream soda, for example, has an energy content of about 300 kilocalories. Dietitians, however, would just say "300 calories".

The calorie is a very small unit. For many applications, a larger unit is used, called the British Thermal Unit, or B.T.U. One B.T.U. is the amount of heat required to raise the temperature of one pound of water by 1° F. One B.T.U. is obviously a much larger unit; it is equal to 252 calories.

Temperature describes the relative hotness or coldness of something.



THE CENTIGRADE THERMOMETER

THE FAHRENHEIT THERMOMETER

2. INTENSE HEAT FROM A STEEL FURNACE

These men are tapping slag from a reverberatory steel furnace in northern Rhodesia. To combat the intense heat, the men wear special protective clothing.

A thermometer is an instrument used for measuring temperature. The thermometer functions on a familiar effect of temperature, called *expansion*. Things usually expand and become larger as they are heated. In hot weather sidewalks and roads buckle as the asphalt or cement expands. Liquids also expand as their temperature increases, and the common mercury thermometer is based on this effect. Such a thermometer is made up of a very thin tube of glass with a mercury-filled bulb at one end. When the mercury in the bulb is heated, it expands and moves up the very thin tube (since the bulb is completely filled, the expanding mercury has nowhere to go except up the tube).

A thermometer can indicate temperature, but we still need a temperature scale to measure the amount of hotness or coldness. Our two most

familiar temperature scales are based on the temperatures at which water freezes and boils. These two temperatures are good standards because they do not vary, and can be easily checked by experiment. In the Fahrenheit scale, the freezing point of water is taken as 32°, and the boiling point of water is taken as 212°. In the centigrade scale these two temperatures are taken as 0° and 100° respectively.

When materials are heated to high temperatures, their molecules radiate energy in the form of light. The colour of this light is a clue to the temperature of the heated object; the shorter the wavelength of the emitted light, the hotter the object. This fact is a common experience, usually described by expressing something as "red-hot" or "white-hot". Steelworkers can measure the temperature of a white-hot steel ingot simply by looking at it through an *optical pyrometer*, a device that indicates the colour of the ingot's glow. In a similar manner, astronomers are able to determine the temperatures of distant stars.

Heat can be transferred from place to place in three ways—by *conduction, convection* and *radiation*. If you hold a metal frying pan over a flame, the handle quickly heats up and you can no longer hold it. The heat travels from the flame to the bottom of the pan and through the metal to its handle. How did the heat move through the metal pan? The kinetic theory of heat gives the following answer: The hot molecules in the bottom of the pan vibrate rapidly because of their temperature, and these molecules bump into their colder, slower-moving neighbouring molecules. The collisions speed up the slower molecules, which in turn transfer their energy to other colder molecules. By this process, called *conduction,* the heat energy gradually travels through the iron pan, and to the handle.

The speed at which heat travels through a material determines whether the material is a good conductor or a good insulator. Most metals, such as aluminum or copper, conduct heat very well, which is the reason they are used in cooking utensils. But materials such as wood, sand or wool conduct heat very poorly. These are insulators. Wool clothing prevents the heat of our bodies from escaping during cold weather.

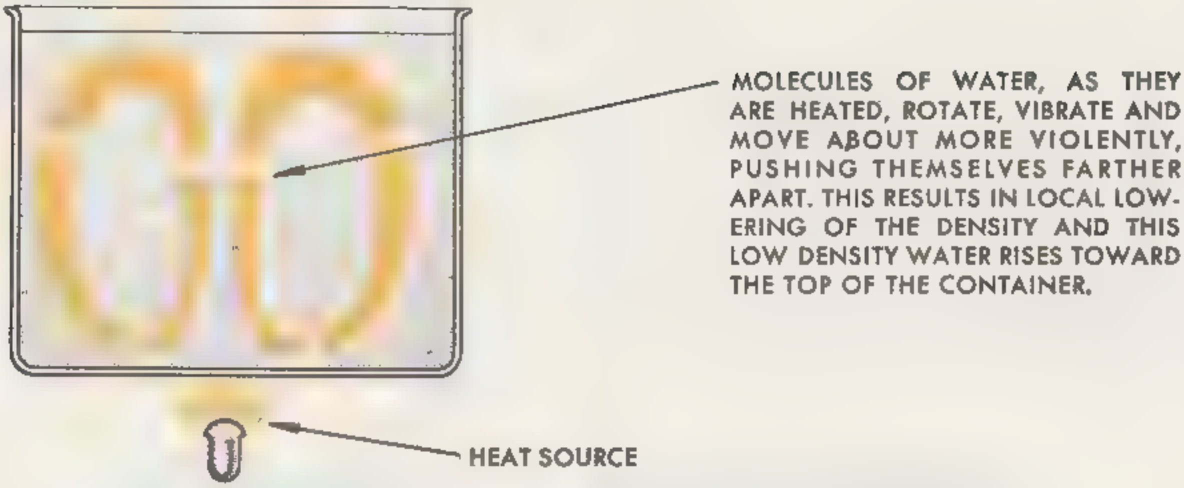
Air and water are also poor conductors, yet heat spreads throughout both of these materials very rapidly. The reason for this is that heat moves fluids in a different manner. Both air and water expand slightly when they are heated. As the water or air expands, it becomes lighter, and rises. At the same time, heavier cold air or water flows down to fill its place. This process is called *convection*. When a pot of water is heated, strong convection currents flow from the top to the bottom of

the pot, until the water boils. Similarly, the air above a hot radiator rises toward the ceiling of a room, while cold air flows along the floor to the bottom of the radiator.

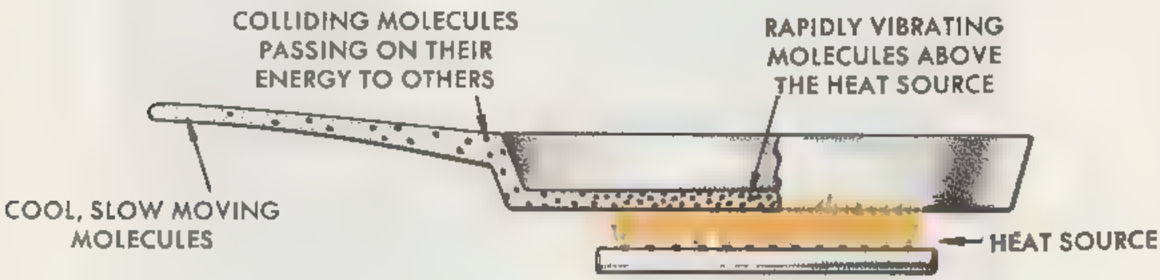
There is yet a third way in which heat energy is transferred. Some ski resorts have swimming pools which are used in the middle of the winter by people clad only in bathing suits. This is possible because the heat of the sun is transmitted directly to the swimmers through *radiation*. The light of the sun contains a great deal of energy, called radiant energy. This energy exists as electromagnetic waves, and can travel through a vacuum. When the sun's radiant energy strikes a per-

This small electric motor literally runs "red hot"—at temperatures of more than 1,400° F. This is said to be the highest temperature at which an electric motor has ever been operated.

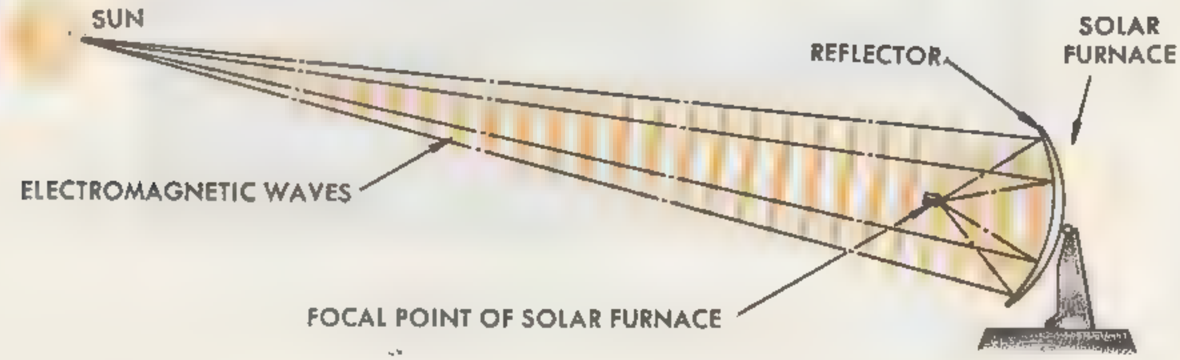
HEATING BY CONVECTION



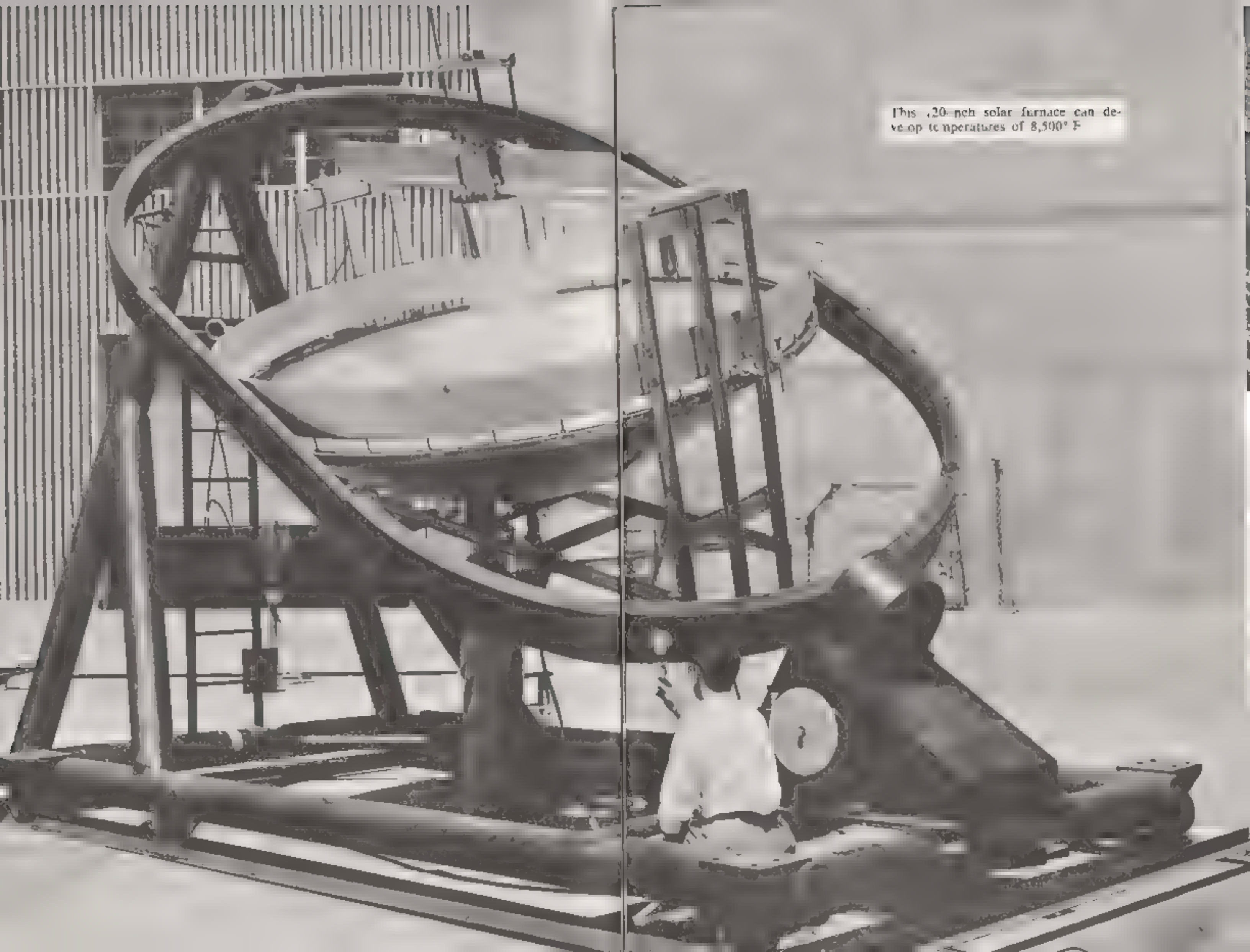
HEATING BY CONDUCTION



HEATING BY RADIATION



A hot-air bag that may save pilots who have bailed out over enemy territory undergoes testing in a laboratory at Goodyear Aerospace Corporation. It consists of a balloon/parachute that inflates as air rushes through the pilot's parachute. A burner (lower center) suspended below the "Ballute", and fed from a tank of butane gas on the pilot's back, ignites. The hot air gives the Ballute sufficient "lift" to halt the pilot's descent and keep him floating out of range of enemy ground fire until rescued.



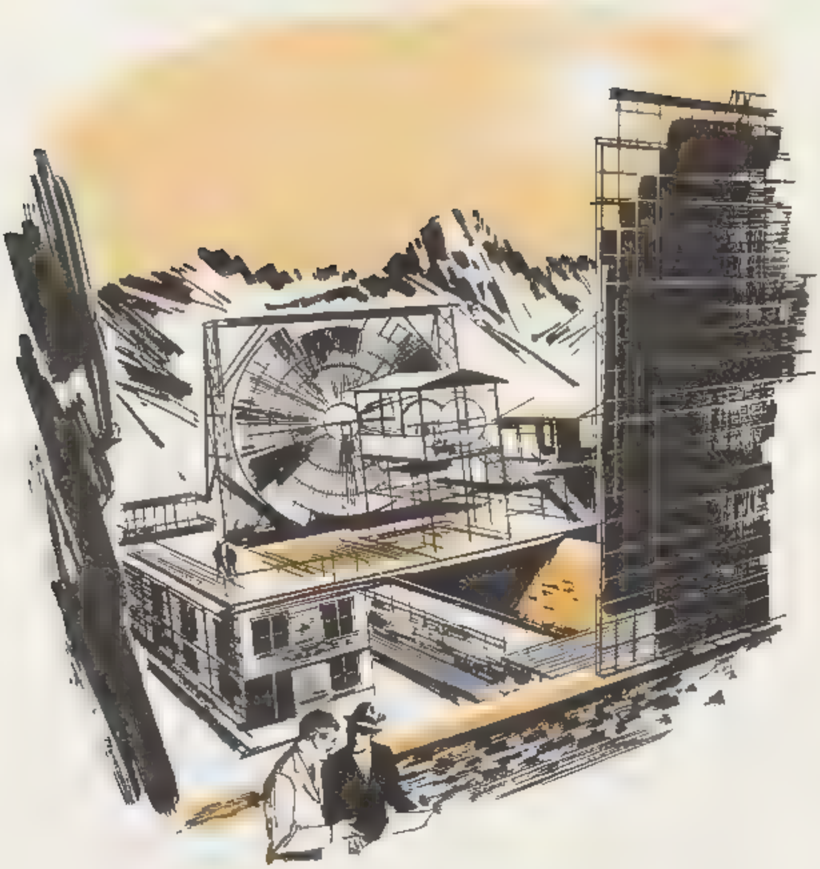
This 120-inch solar furnace can develop temperatures of 8,500° F

son, some of it is absorbed and converted into heat. All the heat of the sun which reaches the earth does so through the process of radiation, since in the vacuum of interplanetary space there are no molecules to transfer heat by conduction or convection. Scientists have built giant mirrors to bring the sun's rays to a focus, creating extremely high temperatures at that point. These are called solar furnaces.

The world's largest solar furnace, located in the French village of Mont-Louis, high in the Pyrenees mountains, consists of a complex of nearly 20,000 mirrors. The mirrors reflect and focus the sun's rays

3. THE ANCIENT ART OF ENAMELING

In this craft shop the ancient art of enameling metalware is updated by the use of modern heating equipment—the oxy-acetylene torch.



Mont-Louis, the world's largest solar furnace, is in the Pyrenees.

on a small "hot spot" less than a foot in diameter. At this focal point the sun's radiant energy is concentrated 20,000 times, producing temperatures in excess of 6,000° F. If a bar of iron is thrust into this focal area, it will melt and bubble in a matter of minutes. Such solar furnaces may eventually become important sources of heat in countries poor in coal or hydro-electric power.

The radiation from the sun is not actually heat itself. The radiation consists of electromagnetic waves of energy, which travel at the speed of light and produce heat in whatever object absorbs them. Much of the radiated energy is carried by invisible radiation, called infrared because it lies just below the deep red end of the solar spectrum.

Infrared rays were discovered around the year 1800 by Sir William Herschel, the English astronomer. Herschel used a glass prism to scatter sunlight into the familiar rainbow-coloured spectrum. When he placed

4. AMERICAN SOLAR FURNACE

This oddly shaped structure is an early-model solar furnace in Natick, Massachusetts.

a thermometer with a blackened bulb in the spectrum, he found that the red light carried more heat energy than the other colours. But when he placed his thermometer in the dark area beyond the red portion of the spectrum, he found that the mercury rose still higher. There could be only one explanation: Some invisible radiation from the sun was reaching the earth and was being transformed into heat. Herschel had discovered the invisible terrain of the infrared—from the Latin prefix *infra,* meaning "below".

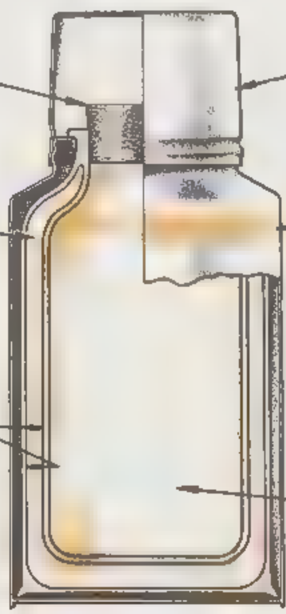
All electromagnetic waves, both visible and invisible, transmit energy. This energy is converted into heat when it is absorbed. But infrared rays are more easily absorbed and converted into heat than other types of radiation. They are sometimes called "heat rays" because they may be felt but not seen.

Some materials absorb radiant energy better than others. Lampblack absorbs about 95 per cent of the radiant energy which strikes it. But a silvered surface, for example, reflects all but 2 per cent of the radiant energy which falls on it. This is why ordinary thermos bottles are silvered—heat cannot radiate into or out of the container.

A thermos bottle is designed to keep foods at constant temperature, either hot or cold. To do this it must prevent heat from entering or leaving the food in any manner. Most thermos bottles are actually two bottles, one inside the other. There is a vacuum in the space between

Materials impervious to heat and fire are badly needed. This is an experimental Beta fabric, tested as a sleeve on an insulated fireproof suit.

them. The vacuum prevents any loss of heat through conduction or convection currents. The glass is also silvered to prevent radiant energy from entering or leaving the bottle. Of course, some heat always escapes through the cork stopper, and the vacuum is never a perfect one.



What Is Cold?

WE NOW HAVE SOME IDEA of what heat is. But what is cold? Cold is the absence of heat, just as darkness is the absence of light. In a cold object, the molecules move about less than they do in a hot object. If all the heat is removed from an object and its molecules no longer move at all, then the object is said to be at the temperature of absolute zero.

Scientists have calculated that absolute zero, the lowest possible temperature, is —273.2° C. Toward the end of the eighteenth century it was discovered that all gases at 0° C. contract 1/273 of their volume for each centigrade degree drop in temperature. The contraction was a clue to the amount of molecular motion within the gas, so the scientists reasoned that at —273° C. all motion of molecules would cease. There would be no heat within the material—its temperature would be absolute zero.

Absolute zero is the lowest temperature that can ever be reached under any circumstances. It has an exact value of —273.2° C. or

Moving from One Scale to Another

SCALE	FREEZING POINT	BOILING POINT	ABSOLUTE ZERO
FAHRENHEIT	32°	212°	459.7°
CENTIGRADE	0°	100°	−273.2°
KELVIN	273.2°	373.2°	0°

To change a Fahrenheit to a centigrade reading, subtract 32 and multiply the result by 5/9.

To change centigrade to Fahrenheit, multiply the centigrade number by 9/5 and add 32.

To change from centigrade to a Kelvin reading, add 273.2.

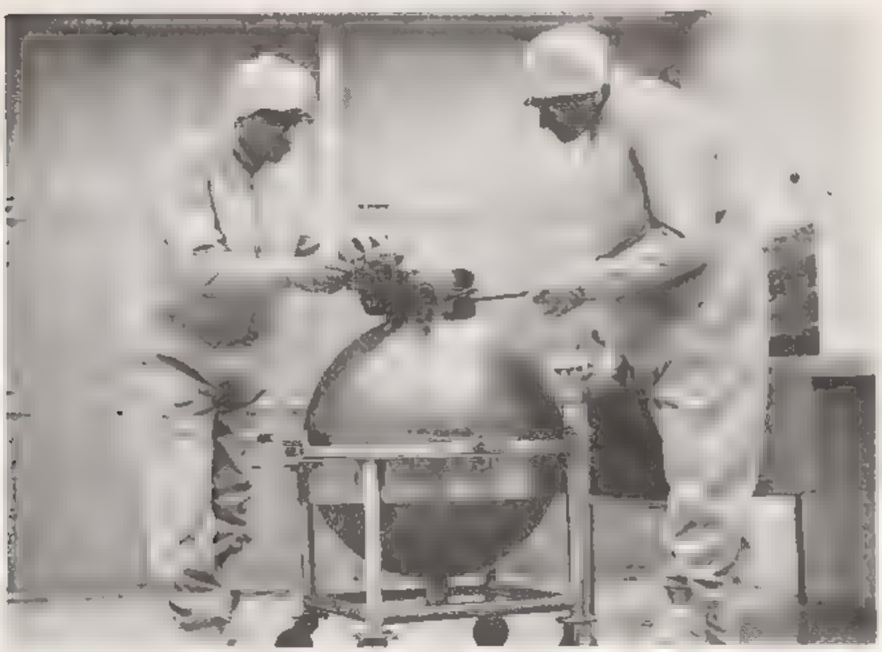
To change from Kelvin to centigrade, subtract 273.2.

To express a Kelvin reading in degrees Fahrenheit, first change from Kelvin to centigrade, then from centigrade to Fahrenheit.

—459.7° F. A third scale of temperature exists, based on the concept of absolute zero. The Kelvin scale assigns the value of 0° Kelvin to absolute zero, while keeping the size of the centigrade degree. For example, the freezing point of water is 273.2° Kelvin, and the boiling point of water is 373.2° Kelvin. The Kelvin scale is most often used by scientists not only to avoid expressing a temperature in a negative figure, but, more importantly, to simplify thermo-dynamic equations and calculations.

The area of science that deals with temperatures near absolute zero is called *cryogenics,* from the Greek *kryos,* meaning icy cold. Many unusual phenomena take place in the super-cold world of cryogenics.

Rubber loses its elasticity when subjected to extreme cold. The left-hand tennis ball, dipped in liquid nitrogen at −340° F., drops with a thud and just rolls. If dropped from a greater height it would shatter!



Three oxygen tanks of this type make up the cryogenic gas storage system aboard U.S. manned flights. Each carries more than 300 pounds of liquid oxygen at temperatures as low as −300° F.

Carbon dioxide, which we know as a gas, becomes a solid at about $-75°$ C., and turns into the familiar "dry ice". Oxygen and nitrogen become liquid at much lower temperatures, lower than 100° Kelvin ($-173°$ C.). It is there that the world of cryogenics truly begins.

At even lower temperatures, at about 60° above absolute zero, oxygen and nitrogen change from liquids into solids, resembling white snow. When metals are cooled to a few degrees above absolute zero, they lose all resistance to the flow of electricity and become superconductors. They conduct electricity without any loss in electrical energy.

Just as some metals can become superconductive, some liquids can become superfluids at cryogenic temperatures. Some superfluids have the unusual property known as "creep"—liquid helium, for example, tends to creep up and over the walls of its container, eventually emptying the container completely. Liquid helium is also a superconductor of heat. Heat waves flow through liquid helium just as sound waves travel through water. This property has been named "second sound".

Cold as we know it on earth is far above absolute zero. The coldest temperature ever recorded on the surface of the earth (outside the laboratory) was $-102.1°$ F. in the Antarctic. This was recorded on an alcohol thermometer. The mercury in a normal thermometer would have been frozen solid at $-38°$ F.

In the outer reaches of space, temperatures do come close to absolute zero. This presents a serious obstacle to the exploration of space, for some materials, such as carbon steel, become very brittle and lose their strength at such low temperatures.

No one has ever seen a substance at absolute zero. Scientists have been able to cool an object down to very low temperatures, but they have never been able to calm completely the motion of the molecules. The lowest temperature ever recorded was achieved with helium in a U. S. Naval laboratory a few years ago. It came close to absolute zero—one microdegree Kelvin—or one-millionth of a degree above absolute zero.

Heat makes life on earth possible. In the immense range of temperature between absolute zero and the temperatures in the interior of the stars there lies a remarkably narrow zone where life has evolved.

The miracle which we call life is pretty much confined to the range between 0° and 50° C., and 32° to 122° F. There are very few organisms that can survive for long at temperatures above or below these limits. It has been estimated that if the average temperature on

earth were suddenly raised or lowered by only 20° C., all life would perish.

But many living things thrive at temperatures that human beings would find unbearable. At the cold end of the scale there is the Alaskan stonefly, which has been observed to mate on the frozen ceilings of ice caverns at the chilling temperature of 32° F. The polar codfish is also one of the coldest creatures; it spends much of its life at 29° F.

It is improbable that life can exist at lower temperatures. Below 32° F. the body chemistry slows or grinds to a halt. If animals survive at all in such low temperatures, it is only because normal activities, such as metabolism, come to a standstill. Animals may enter into a state of hibernation, which is a state of suspended activity. The ground squirrel hibernates in winter when the air temperature drops to 32° F. but its body temperature does not drop much. Some bacteria can survive for months at temperatures near absolute zero. Other living things, such as spores, pollen grains and seeds can remain frozen for years at a time, only to recover their activity the moment they are warmed. In recent years, some patients undergoing heart surgery have been chilled by ice water in order to reduce their body temperature during the operation. At lower temperatures, their bodies require less blood and oxygen, so that the delicate heart surgery can be performed at less risk.

Life at high temperatures is also possible. At the hot end of the scale is one of the hottest of all animals, the cold-blooded fish *Barbus Thermalis* which lives in the hot springs of Ceylon at a temperature of 122° F. and as a result has a high body temperature. The albino mouse lives at a body temperature of 102° F., and songbirds have a normal temperature of 110° F. Simpler forms of life can thrive at even higher temperatures. Some bacteria multiply at 158° F. In the hot pools of Yellowstone an adaptable blue-green algae carries on its life processes at a simmering 185° F.—only twenty-seven degrees from the boiling point of water.

While we know that heat makes life on earth possible, scientists want to know why cold, especially very cold water, kills.

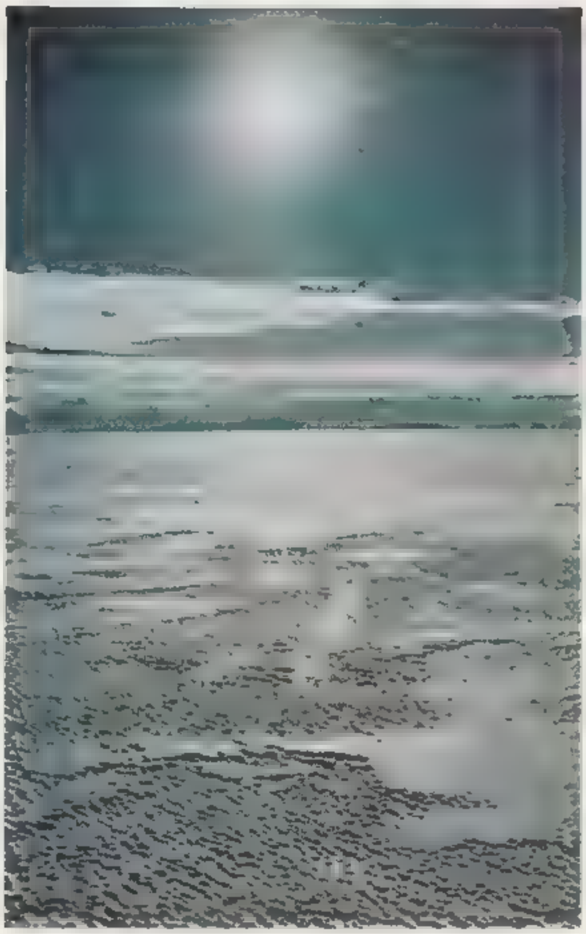
Several research projects are under way to learn what happens to a person's breathing, circulation and muscular responsiveness in cold water —50° F. or less.

As we know, the farther man ventures from earth—whether above or below it—the colder it gets. Cold exposure was a factor in 1973 in the death from carbon-dioxide poisoning (suffocation) of two scientists who spent more than a day in a minisub on the ocean floor after it had become en-

snarled in debris from a scuttled destroyer. They were in a part of the sub which was constructed of aluminum—permitting a more rapid heat loss, while two other scientists aboard the same sub in another section made of plastic survived.

Controlled cold, like an air-conditioning system, provides much comfort during the hot summer months. Air conditioning does not cool by adding cooling, but by removing heat and humidity. The system is made up of four components: the cooling coil which removes the heat and humidity; the condensing unit, located outside the house to pull heat from inside; refrigerant tubing which transfers heat from the cooling coil to the condensing unit; and finally the thermostat which controls the operation of the whole system—and measures only the temperature, not the humidity.

When temperatures are constantly below 32° F. animal body chemistry slows down to a halt. That is why there are so few living things to be found in the vast Antarctic wastes.



5. ANTARCTICA

The Body's Catalysts

THE KEY to the relation between temperature and life lies in the effect of heat upon *enzymes,* the body's catalysts. The presence of enzymes accelerates chemical reactions within the body. But enzymes are large, complex protein molecules, which are very sensitive to heat. In every organism there are many enzymes, and each catalyzes a specific chemical reaction. Heat can break down enzymes or change their effectiveness. Most living things have a temperature at which they function best. At lower temperatures, enzymes are less effective and chemical reactions slow down. At higher temperatures, some of the delicate enzymes may break down, again slowing chemical reactions. In both cases—excessive heat or excessive cold—the activity of life is reduced.

The sun's heat, which continually stirs up the blanket of air enveloping our planet, is responsible for the changes in the atmosphere which we call weather.

A hurricane, for example, uses heat energy to achieve its violent force. A hurricane always begins as a tropical storm, even if it sweeps far to the north. A hurricane can form only over the tropical ocean where the water temperature is above 27° C. (81° F.). The warm water areas of the southern North Atlantic, the Caribbean and the Gulf of Mexico are good spawning grounds for hurricanes. Hurricanes which are born in the South Pacific are called typhoons. These are simply hurricanes with an Oriental name. Occasionally, a hurricane forms off lower California. But hurricanes seldom form in latitudes above thirty degrees north or south.

Where does a hurricane obtain its terrible power? The primary source of a hurricane's energy is the heat in the ocean. As the sun warms the ocean, water on its surface evaporates and becomes part of the atmosphere. Each molecule of water vapor carries away with it the heat of the sun that changed it from a liquid to a vapor. When these vapor molecules join together to become water droplets, they give up their *latent heat*. This heat warms the air surrounding the droplets, causing the air

Helicopters, work horses of the Coast Guard's air fleet, often provide the only immediate way of rescuing survivors from hurricanes. Here a man is hoisted aboard a Sikorsky HH-52A after a hurricane named Betsy.

to rise and expand. In this way the ocean's heat is converted into powerful currents of air that make up a hurricane.

As long as the hurricane has water vapor, it has its "fuel". Hurricanes often lose their power as they pass over land, because they dry up and because of friction between the winds and the rough ground. However, many gain new energy as they approach the sea again; in sailor's jargon, they "get one foot in the water". After moving far enough from the tropics they finally move out over the ocean areas that are too cool to supply much vapor.

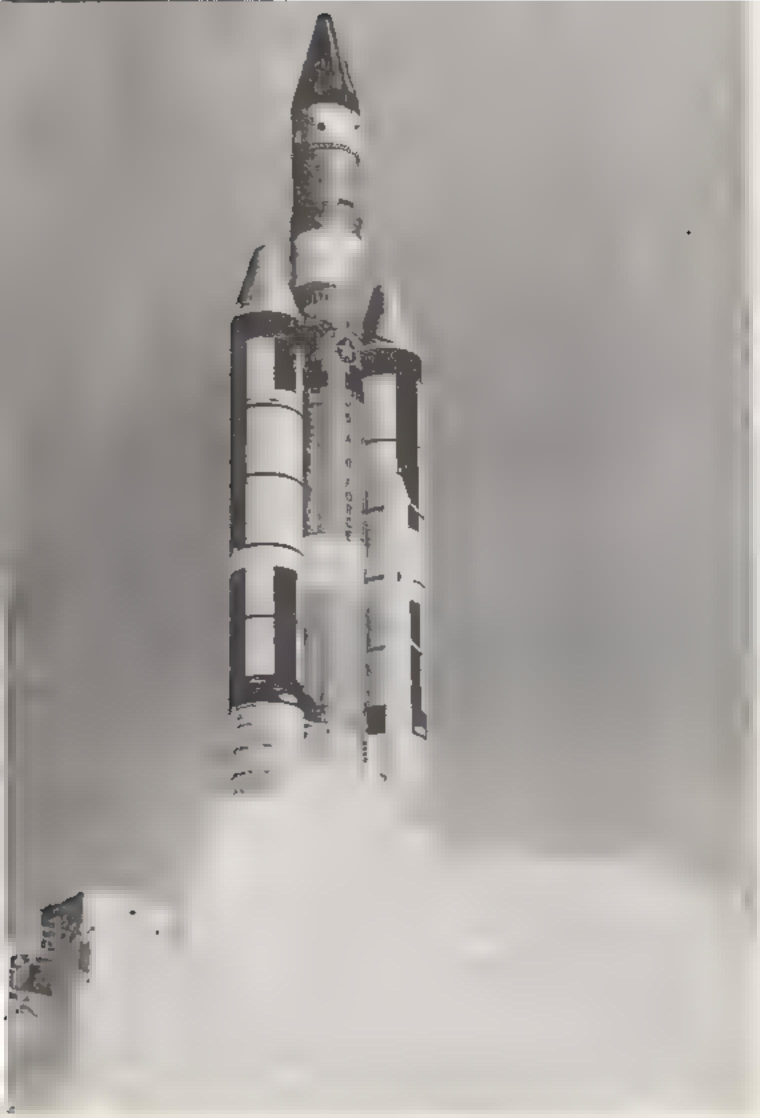
Weather scientists hope that they may some day be able to control hurricanes or at least alter their destructive paths by taking advantage of the hurricane's dependence on water vapor. One way to fight a hurricane might be to "seed" its clouds while it is still young, forcing the clouds to release their rain quickly, before a deadly hurricane can form.

Some people think that the government should explode nuclear bombs in the eye of the hurricane, in the hope that the explosion would snuff it out. But a hurricane is millions of times more powerful than any nuclear bomb. The bomb would *add* heat to the storm—not to mention the radioactive fallout!

Scientists do not care to rush in with cures for hurricanes until they gain a fuller understanding of these storms and the atmosphere in general. Until then, they will be very careful in attempting any large-scale efforts to control weather.

Friction—the Re-entry Problem

When an earth satellite, such as a man-in-space capsule, is lifted into orbit, the heat energy of tremendous rocket engines is transformed into the motion of the satellite itself. To stop the motion of a satellite and bring it back down to earth, its energy of motion must be changed once more to heat energy—the same tremendous heat energy



With its giant motors supplying 2.4 million pounds of lift-off thrust, this Titan III launch vehicle generates tremendous heat energy.

that once lifted it into orbit. No wonder that this situation, once called the "re-entry problem", was at first thought to be insoluble.

A space vehicle returning from the moon enters the earth's atmosphere almost as fast as meteors do. Meteors are slowed by the atmosphere, but nearly all of them melt and vaporize under the intense heat of friction with the air. When a man-carrying spacecraft first enters the atmosphere, a shock wave of highly compressed air forms just ahead of its blunt nose, heating the air in this region to about 11,000° F. At this temperature the air glows and heats the capsule by direct radiation and conduction.

Why does a space capsule have a blunt nose rather than a thin needle-like nose which we often see on supersonic planes? If the capsule were sleek and streamlined it would be slowed by the friction of the air flowing along its surface. The capsule would have to absorb all the heat generated as the result of its deceleration, and would quickly melt and

Science Bulletin

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ALTERNATIVE POWER SOURCE

An alternative power source that could become competitive to existing fossil fuel and nuclear plants was proposed by fuel chemist Albert J. Giramonti of United Aircraft Corp.

Called COGAS, for Combined Gas and Steam Turbine Systems, the technique would use gas obtained from low quality coal or residual oil. The gasification and desulfurization processes would make the fuel expensive by today's standards, but as pollution controls tighten and technology advances, Giramonti said, COGAS stations would be able to compete economically with both nuclear and conventional fossil fuel installations.

Gasification involves partial oxidation of the raw material in a high-pressure reactor, followed by various scrubbing and absorption operations. Valuable elemental sulfur is produced as a by-product. The first COGAS stations could be built immediately with existing technology, Giramonti said.

A SWIM WITH ANTIFREEZE

Fish in Antarctic waters are able to keep alive and swimming in temperatures that would freeze a temperate-water fish's blood solid in its veins, thanks to a form of natural antifreeze called a glycoprotein.

Seawater in temperate regions freezes at about 28.7 degrees F., which is just about the temperature at which the ice-laden waters of Antarctica manage marginally to

stay liquid, reports Arthur L. DeVries of Scripps Institution of Oceanography. The blood of a temperate fish freezes at 30.6 degrees, he says, with most of the difference between that and the freezing point of fresh water due to sodium chloride (salt). An Antarctic fish's blood, however, will stay liquid down to 27.5 degrees, and indeed there is a slightly higher concentration of salts. DeVries' studies, though, suggest that less than half the credit for this lowered freezing point is due to salts. The rest is caused by the presence in the blood of glycoproteins, proteins containing carbohydrates.

These glycoproteins, the researcher says, are more effective in lowering the freezing point of water than either salts or ethylene glycol (automobile antifreeze). The effectiveness of the glycoproteins seems to depend not upon their concentration, but upon some sort of interaction between the glycoproteins and water or ice.

TAKING EARTH'S TEMPERATURE FROM SPACE

NOAA 2, an environmental satellite, is now taking 1,200 to 1,400 temperature soundings of the earth's atmosphere daily and transmitting the readings to ground receivers. From the ground receivers they are distributed to weather stations around the world. The satellite covers every portion of the globe twice a day, providing atmospheric temperature measurements over land and ocean in clear areas up to an altitude of twenty miles.

The measurements are used to calculate the vertical temperature distribution from which is derived total moisture content—information extremely useful in weather forecasting.

EARTH'S WEATHER AND THE SUN

The evidence for effects of solar activity on the climate and weather of earth is becoming stronger,

although the mechanisms for these effects are not fully explained. Anatolii V. D'yakov has won official recognition in the Soviet Union for his theories of long-range weather forecasting—that solar activity influences weather not only through variations in heat flux, but also through other forms of radiation. D'yakov asserts that the sunspot activity and variations in the solar wind should also be taken into account in long-range forecasting.

Earlier evidence of solar influence was from systematic variations in the widths of growth rings in trees with the solar cycle. Later, the Soviets found similar evidence in variable silt deposit layers in the Aral Sea and Lake Victoria, which they claim can be used to trace the solar cycle back for millions of years.

PREDICTING WHERE TO TAP THE EARTH'S HEAT

With supplies of oil, natural gas and coal constantly dwindling, the search is on for new sources of power. One of the most promising is geothermal and Robert Smith of the University of Utah believes he has found a way to spot geothermal features.

Smith has found a correlation between thermal activity and earthquake swarms—concentrations of frequent tiny earthquakes—by plotting all the earthquakes, hot springs and mud spots in the western United States. He and his assistants have identified significant earthquake zones from southern Utah through Montana and in central Idaho that may be associated with potential sources of geothermal energy.

The seismic belts interest in Yellowstone Park, a known geothermal area, and near Cedar City, Utah. Seismographs installed in Yellowstone recorded up to fifty earthquakes a day, and in the Cedar City area, over a thousand quakes a day were detected in a November 1971 swarm. Says Smith, "The prospect of pollutionless hydroelectric plants in Utah is very real."

COAL GASIFICATION PROGRESS

Coal gasification techniques now at the pilot plant stage promise to turn a dirty fuel into a clean one. The basic chemistry is simple and long-known: Coal is reacted with steam to form methane, carbon monoxide, hydrogen and carbon dioxide. The product can be upgraded to nearly pure methane. But there are problems in both steps. Some coals tend to cake, some need pretreatment and some coals produce pollutants that get into the gas.

Arthur M. Bueche, of General Electric Company, reports that GE has overcome some of the problems. Use of inert diluting agents prevent caking in GE fixed-bed gasification reactors; an extrusion process makes possible the use of a variety of coals without pretreatment; and new GE membranes, designed for medical applications, are effective for removing certain pollutants selectively from gas.

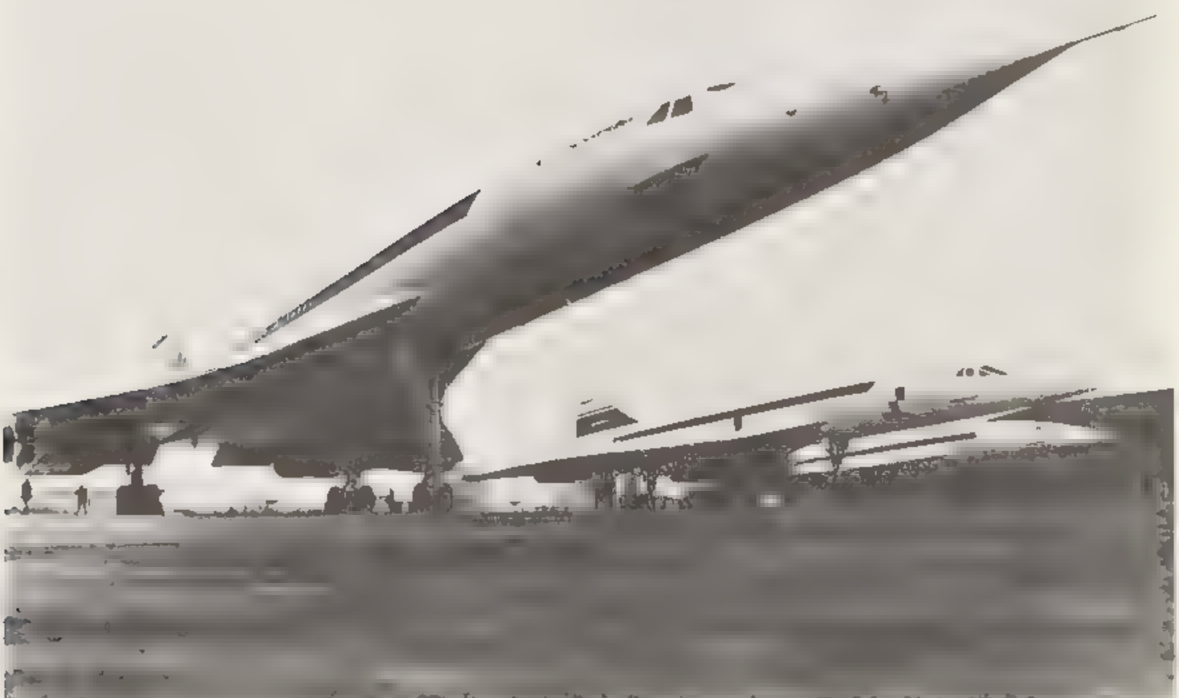
COOKING BY THE SUN

Conventional heat sources for cooking are all polluting, because they involve fuel burning either at the site of the cooking or in a power plant. Solar stoves have been unattractive because they are unreliable and unwieldy or because they do not suit certain ethnic cooking styles.

Charles J. Swet, of the Johns Hopkins University's Applied Physics Laboratory, reported on a new design for a solar stove which he says overcomes the liabilities of earlier models.

"A reflector, a parabolic cylinder, concentrates the incident solar energy onto a heat pipe for delivery to a conveniently located hotplate. The reflector follows the sun by rotating about the fixed heat pipe, which is parallel with the earth's axis. . . . The condensing hotplate may be used as a griddle or as the heat source for a variety of utensils."

vaporize. But a blunt nose creates a strong shock wave of intensely hot air which moves away from the capsule, almost at right angles to it. Thus most of the heat is absorbed by the atmosphere rather than by the capsule itself. The shock wave deflects a great deal of the heat energy away from the capsule. All that is needed then is a good insulator or heat absorbing material on the face of the capsule. Scientists have discovered that layers of ordinary Fiberglas make a good material for this purpose. Under the intense heat the outer layers of Fiberglas char, melt and vaporize. This combination of processes is called *ablation*. Not only does the process of ablation absorb a good deal of heat, but the vaporized glass on the surface of the heat shield prevents heat from flowing from the hot shock layer into the capsule.

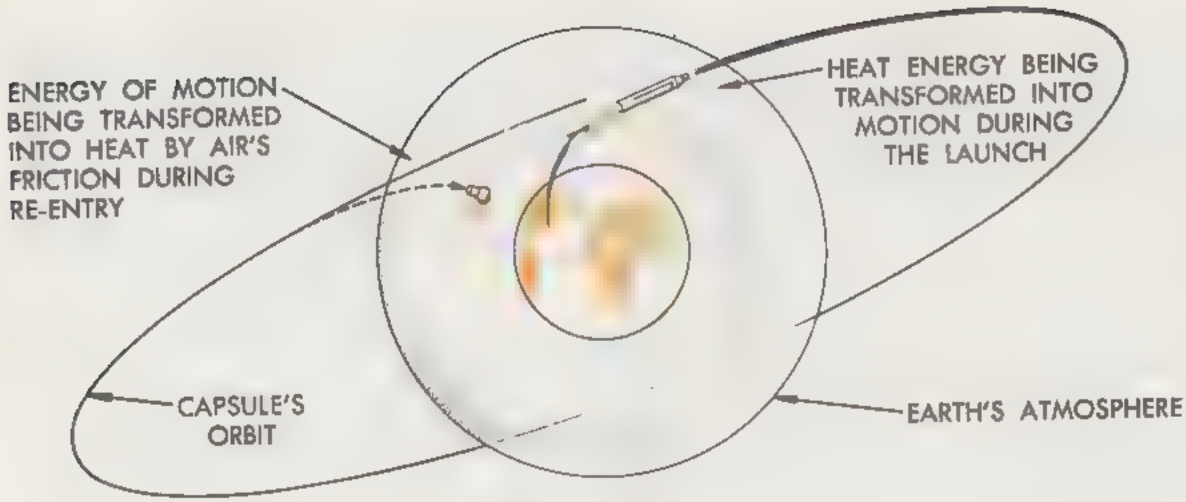


The needle-shaped nose of the Concorde supersonic passenger airplane, built in England and France, keeps to a minimum the shock waves which strike the aircraft during speeds as high as 1,400 miles an hour.

A supersonic plane, on the other hand, must create shock waves which are as small as possible. Otherwise the plane's engine will not be able to push it to higher speeds—all the engine's energy will be used to generate a larger shock wave. For this reason supersonic planes have specially designed needle-shaped noses which greatly reduce the shock waves. But the friction of the air along the surface of the plane may be sufficient to heat it red-hot. Supersonic planes carry the pilot and his instruments inside what amounts to a refrigerator, in order to save him from being broiled alive within a red-hot plane, and to keep the instruments from melting.

6. HYPERSONIC SHOCK TUNNEL

Scientists at General Electric's Research Laboratory use a hypersonic shock tunnel to study previously unexplored regions of high-speed flight. The device simulates the extremely high velocities and temperatures that a missile or space vehicle encounters when re-entering the atmosphere.



What Is Fire?

TO UNDERSTAND FIRE we must first understand the chemical reaction called *combustion*. The concept of combustion was discovered during the years 1777 to 1783 by the brilliant French chemist, Antoine Lavoisier. According to Lavoisier, the term combustion can be used to describe any heat-producing chemical reaction. Before Lavoisier it was generally thought that fire was a substance which flowed from one material to another. In the Middle Ages, alchemists considered fire to be one of the four fundamental elements of which the world was made (earth, air and water were the other three).

Fire can be thought of as any combustion process intense enough to emit light. It may be a quietly burning flame or the brilliant flash of an explosion.

A typical combustion process is the burning of gasoline in an automobile engine. The vaporized fuel is mixed with air, compressed in the engine's cylinder, and ignited by a spark. As this fuel flames up, the heat produced flows into the adjacent layer of unburned fuel and ignites it. In this way a zone of fire spreads throughout the fuel mixture until the combustion is complete. This moving zone of burning fuel is called a combustion wave.

The speed at which such a combustion wave travels through a fuel

mixture is called the burning velocity of the mixture. The burning velocity of a gas such as methane quietly burning in air is only about one foot per second. By comparison, the burning velocity of more reactive combinations such as the rocket fuels, hydrogen and fluorine, can be hundreds of feet per second.

If the fuel flows at the same speed as the combustion wave, the result is a stationary flame, like the one in a kitchen gas burner. In the kitchen burner a jet of gas mixed with air flows from the openings in the head of the burner. If the velocity of the fuel mixture flowing from the opening is greater than its burning velocity, the flame blows out.

In jet engines speeding through the air at 500 or 600 miles per hour, the engine's flame is sometimes blown out by the blast of air entering the combustion chamber at high speeds. Jet pilots call this condition "flameout".

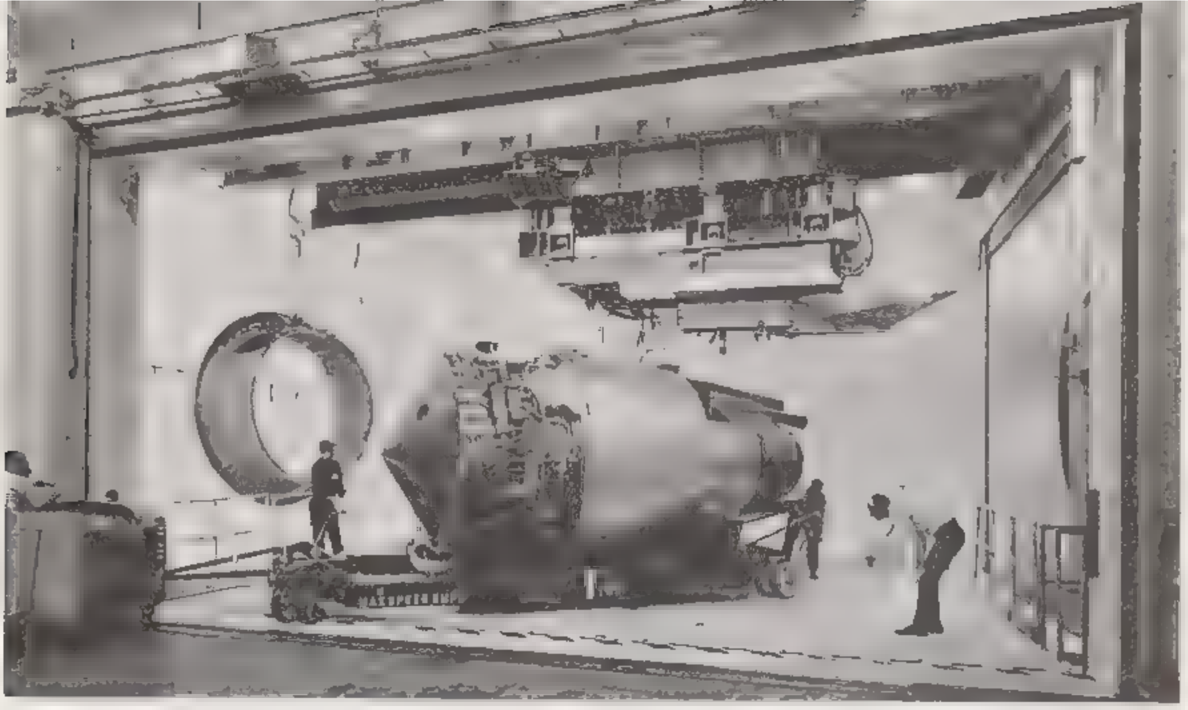
Combustion can sometimes occur very slowly. A familiar example of slow combustion is the drying of ordinary oil-based paint. In this chemical reaction, called *oxidation,* the oxygen in the air reacts with the drying oil in the paint to produce a tough film. The linseed oil molecules link together, forming an insoluble coating. Another example is the hardening and cracking of rubber with age. One way to avoid this is to incorporate certain chemicals called inhibitors into the compound.

How can the chemical reaction involved in such a quiet process as the drying of paint also produce spectacular flames and explosions? The main difference between the two is the temperature at which they occur.

At lower temperatures the reaction must take place over a long time. The heat which is slowly produced is dissipated to the surroundings and does not speed up the reaction. When the heat produced by the low-temperature reaction is retained instead of being dissipated, the system breaks into flame. This is the process that accounts for a major fire hazard, spontaneous combustion, as when oily rags suddenly burst into flame.

In a flame or explosion, the reactions are extremely fast. In many chemical processes, however, such a rapid oxidation process would be extremely destructive.

A graphic example of rapid combustion is shown in these two photos showing a rocket-propelled Sparrow missile streaking from beneath the wing of an F-104 Super Starfighter, and then (below) outdistancing the jet plane in moments.



Thanks to thorough testing in a test cell such as this, jet engines aboard giant airliners seldom, if ever, "flame out".

One important place where violent combustion is suppressed is in the human body. In the complicated series of steps by which oxygen is used to obtain energy from the food we eat, all the heat is released slowly. Some biochemists believe that vitamin E protects many body substances against the destructive effects of possible violent combustion.

Thus the chemical processes of life are linked to the flame that powers the jet engine.

Man-made Diamonds

NATURAL DIAMONDS were formed in the earth many millions of years ago, by a combination of tremendous pressure and high temperature. A temperature of at least 3,000° F. and a simultaneous pressure of a million pounds per square inch are about the minimum requirements for the creation of diamonds. These conditions existed deep in the earth millions of years ago. But until recently scientists had been unable to re-create these conditions in the laboratory.

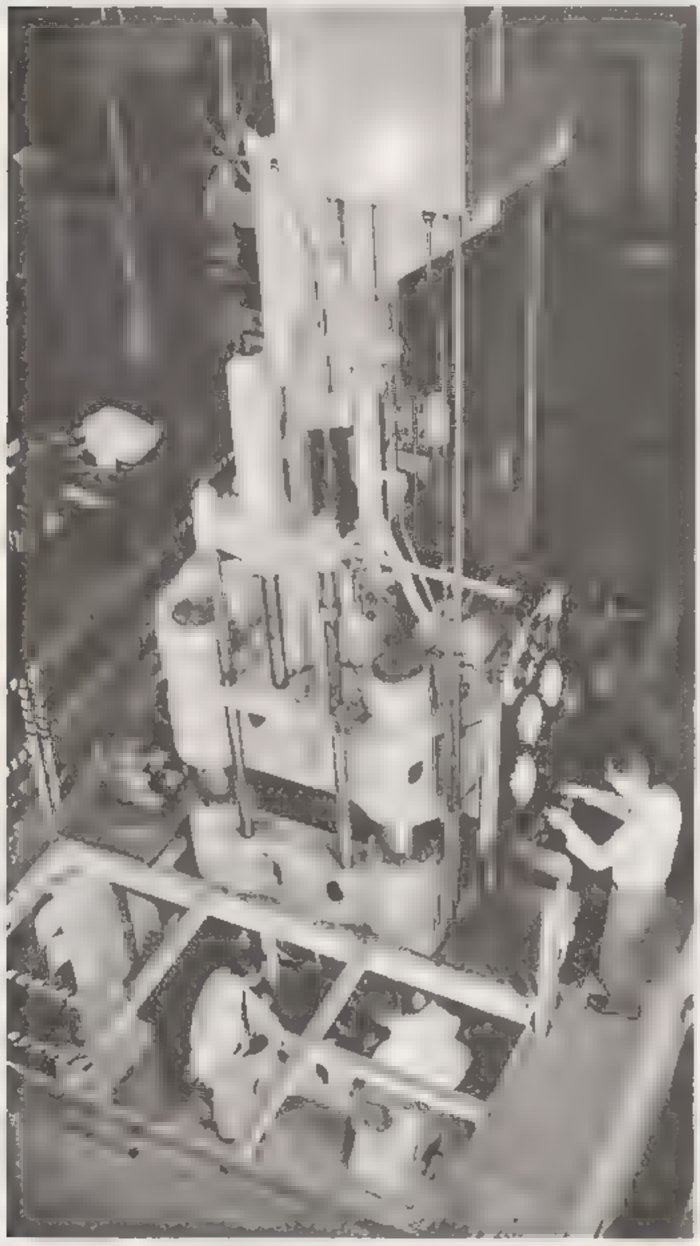
In 1955 a group of scientists at the laboratories of the General Electric Company gathered around a huge hydraulic press. One of the largest in the world, the press could generate pressures as high as 1.6 million pounds per square inch. With this formidable machine the scientists hoped to squeeze ordinary carbon so as to transform it into precious diamond crystals. As they turned on the press, they crouched

These GE diamonds were created in 1970 in the laboratory from graphite, the soft black substance used in "lead" pencils. These diamonds have undergone slight polishing, but they have not been cut and retain the shape in which they were "grown" in a special apparatus for subjecting graphite (the pile of black powder) to extreme pressures and temperatures.

These man-made diamonds—some ranging up to one carat in weight—come in a variety of colours—including various hues of blue and yellow.

This gem diamond created by GE is three-quarters of a carat in weight. Man-made gem diamonds are currently many times more costly than those dug from the ground, and the company does not know whether synthesized diamonds can ever compete economically in the gem market.

behind a concrete barrier in case of an explosion. But the huge two-story-tall machine did not explode. It directed its tremendous pressure on a tiny sample of graphite (carbon). At the same time, the graphite was heated by an electric current to a temperature of 5,000° F. As they later examined the remains of the graphite powder under a microscope, the scientists discovered tiny diamond crystals. They had achieved one of the oldest dreams of science—changing common carbon into precious diamonds. At first, the man-made diamonds were very small or microscopic and of greatest usefulness in industry rather than for jewelry. But by 1970, research had led to production of gem-quality diamonds.



This 1,000-ton hydraulic press exerts pressures of 1.6 million pounds per square inch on an area of one square inch. It was this GE press that produced the first man-made diamonds.

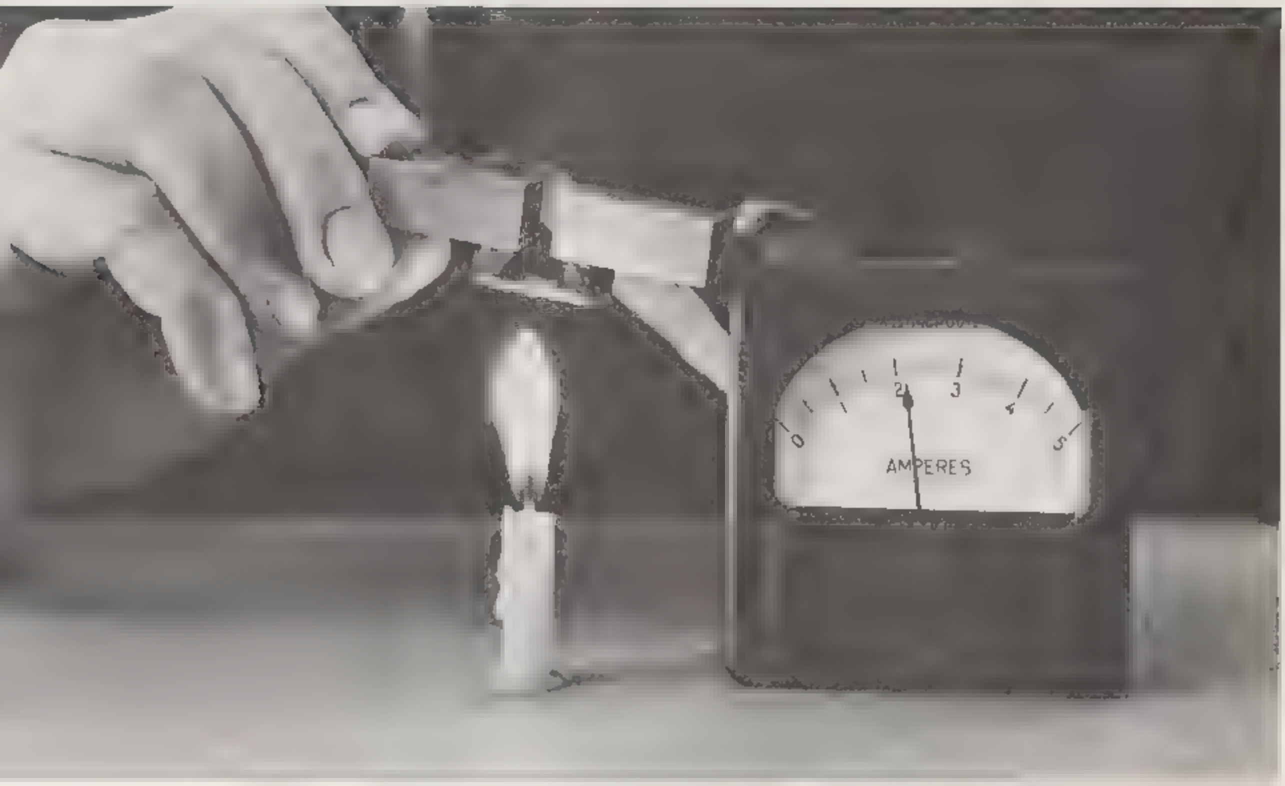
The world's most powerful floodlights—20,000-watt Xenon compact-arc high-intensity lamps—provide illumination for the launching of an Apollo flight to the moon.

From Heat to Electricity

THERMOELECTRICITY, THE DIRECT CONVERSION of heat into electricity —or electricity into heat—was discovered in the early 1800s at a time when all the great scientific minds of Europe were intrigued by the secrets of electricity and magnetism they had unearthed in their laboratories.

One such scientist was Thomas Johann Seebeck (1770–1831). Seebeck was born in Prussia. His father was a rich merchant whose fortune left Seebeck free to pursue any career he wished. In 1802, Seebeck obtained his medical degree and then devoted his life to the study of science.

Seebeck's most important research was in electricity. On one particular day in 1823 he joined two different electrical conductors in a closed circuit, and held a magnetic compass needle near the circuit. He found that when he heated the junction of the two conductors the magnetic needle was deflected.



When the flame of the candle is used to heat the junction of the two dissimilar thermoelectric materials—the two short black cylinders—more than two amperes of electric current are produced in this demonstration.

Seebeck's observations immediately caught the attention of his fellow scientists, and after much discussion they interpreted his experiment as follows: The heat had generated an electrical current in the wire. The flow of this current had created a magnetic field which in turn had deflected the compass needle. The scientists concluded that Seebeck had discovered thermoelectricity, the direct conversion of heat into electrical current.

But Seebeck was not impressed by this interpretation of his experiment. He believed that the heat had generated a magnetic force in a direct way, without an electrical current. Seebeck rejected the concept of thermoelectricity. He regarded exponents of the thermoelectric theory as following a fashionable trend.

In trying to disprove thermoelectricity, Seebeck experimented with a variety of metals, alloys, minerals and other inorganic compounds. He listed these various substances according to the strength of their thermo-

Reversing the process, and passing direct current in one direction through the junction, produces heat and makes the water in the small beaker boil.

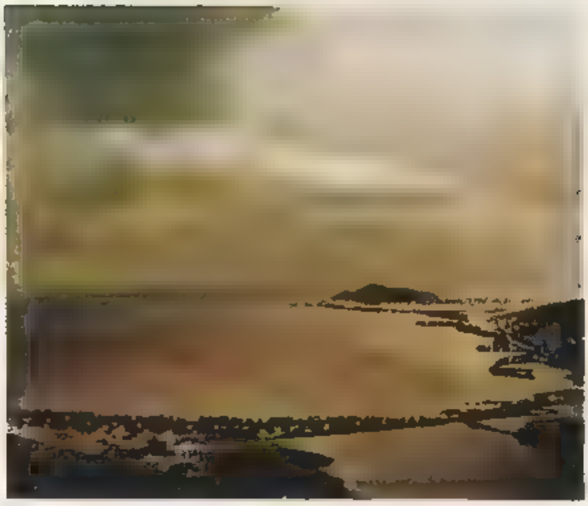
electric properties. If he had made a junction of the first and last substances in his list, zinc antimonide and lead sulfide, he would have been able to convert heat into electricity with an efficiency of 3 per cent —an efficiency as great as that of the best steam engines of his time. This very combination of materials was used over 100 years later in one of the first efficient thermoelectric cells ever made, designed by Dr. Maria Telkes of the Westinghouse Research Laboratories in the United States.

Twelve years after Seebeck's discovery, Jean Charles Peltier, a French amateur scientist, observed an unusual temperature change at the boundary between two different conductors when a current was made to pass through the junction. This was just the reverse of Seebeck's discovery! In Seebeck's experiment, heat produced an electric current. In Peltier's experiment, electric current produced a hot or cold junction.

But Peltier also did not believe in the phenomenon of thermoelectricity. Like Seebeck, Peltier had developed his own theories on the nature of electricity.

However, the existence of thermoelectricity could no longer be denied after the year 1838, when Emil Lenz, a Russian scientist belonging to the Academy of Sciences in St. Petersburg, performed a simple experiment. He placed a drop of water on a junction of bismuth and antimony rods. When electric current was passed through the junction, the droplet

Changing the direction of the direct current produces thermoelectric refrigeration.

7 MIDNIGHT LIGHT—FROM A NUCLEAR BLAST

Left: At 10:59 P.M. on the night of 8 July, 1962, this was the scene over Oahu in Hawaii. *Right:* One minute later the whole sky lit up—a nuclear test device had exploded hundreds of miles away, turning night into day. The energy was released as radiation, sound, light and intense heat.

immediately froze to ice. When the direction of the current was reversed, the ice melted. There could be only one explanation: The electric current absorbed or generated heat at the junction of the two metals.

The discoveries of Seebeck and Peltier were laboratory curiosities for over a hundred years because the thermoelectric currents which the two scientists had generated were so extremely weak that no practical use was foreseen for this phenomenon. Only one application for the Seebeck effect was found during this period, a device which could measure temperature.

When the ends of two dissimilar wires are twisted together (making a thermocouple) and their other ends are connected to a sensitive detector of electric current, such as a galvanometer, current will flow through the circuit. The flow of current measured on the galvanometer indicates the temperature at the junction where the two wires are twisted. Thermocouples rarely develop an electrical potential greater than a few millivolts (thousandths of a volt).

Thanks to the development of the transistor, however, the discoveries of Peltier and Seebeck are once more being studied by research scientists.

The transistor was the result of research on an unusual class of substances called semiconductors—materials which can conduct only small amounts of electric current. They are poorer conductors than metals, but better conductors than insulators, such as glass.

It was found that some semiconductors show a thermoelectric effect many times greater than that of metals or other substances. They make it practical to transform heat directly into electricity without machinery such as engines or generators. To achieve this, two different semiconductor crystals are joined together at a *junction*. The junction of the crystals is kept hot, while the cold ends of the crystals are maintained at a lower temperature. The heat causes current to flow through the

A toy train speeds around track powered by electricity from a thermoelectric generator. The generator consists of a propane torch heating several thermoelectric junctions, thereby providing a 10-watt power source.

junction, and an electrical circuit, which may include a lamp or motor.

The best semiconductor junctions convert about 15 per cent of the heat energy they receive into electrical energy. By comparison, a steam-driven electric power plant converts heat into electricity at an efficiency of about 30 per cent. But steam turbines have been continually improved upon for the last fifty years, while thermoelectric cells are relatively young.

Electricity can be used also to absorb or release heat from a thermoelectric junction, according to the Peltier effect. If the current is made to flow through the junction, it will either heat it or cool it, depending upon the direction of the current. If the current flows across the junction in the correct direction, it extracts heat from one end of the junction and delivers it to the other end. When used in this manner, a thermoelectric cell acts as a refrigerator.

Peltier junctions have already been used in the design of thermoelectric refrigerators which have no compressors, fans, or other moving parts. However, they are still far from common.

Solar Energy

THE MOST IMPORTANT APPLICATION of thermoelectricity may eventually be the harnessing of solar energy to meet the increasing demand for power—a demand which has prompted scientists to take a closer look at the sun's potential for meeting this need. If only a small part of the sun's energy could be captured economically it would go a long way toward meeting our burgeoning energy needs. Consider that energy from the sun falls on the surface of the earth at the fantastic rate of 100,000 billion kilowatts—one million times the rate of power production of all the electric plants throughout the world. In just a few days the sun supplies more energy than is contained in all the known coal and oil reserves which accumulated in the earth over millions of years.

Coal and oil are the remnants of green plants which once absorbed solar energy and transformed it into potential chemical energy. But plants convert only one per cent of the sun's radiation into usable energy. Thermoelectric generators may eventually convert as much as fifty per cent of the sun's radiation into usable energy. The consequences of this possibility are staggering.

While converting sunlight into electricity for use on earth is well into the future, electrical power aboard Skylab, the first orbiting space station, was developed by solar cells from the sun's rays. The sun was both an

asset and a threat to the successful completion of that historic mission in 1973. An aluminum shield which was to protect the crew from the sun's heat tore loose as the Skylab spacecraft rocketed into orbit, and other problems struck the solar cells. As a result the temperature hit 130° F. in the craft and power was greatly reduced, threatening the mission. Astronauts, however, were able to erect a parasol-like sunshield over the spacecraft to lower the temperature inside the craft so they could conduct their experiments. Then during a long space walk they were able to free one of two jammed solar wings to increase the electricity in Skylab. Before these repairs they had to manuever the spacecraft in and out of the sun to keep it cool enough to live in.

Back on earth, men are experimenting with ways to capture the sun's energy so that it is available when needed. Take a pond, for example. Solar heat can literally be stored in a pond. The bottom of the pond is covered with a heat-absorbing material such as black butyl rubber which, in turn, heats the water. Warm water, as you know, rises, but salt will make it heavier and it will stay at the bottom of the pond with the lighter surface water as an insulator. The boiling water can be used with a low-temperature generator to make electricity.

What would happen if these "solar farms" were blanketed for a time by rain, fog or haze? Why not utilize giant power-generating satellites to convert sunlight to electricity in orbit and relay the power to earth over microwave beams? This is a suggestion by one scientist. But it is probably decades away because even earthbound solar collectors are very expensive.

The direct use of solar energy can be very practical, and in some sections of the country it is cheaper than electric heating. For example, a California company sells a relatively inexpensive solar heating system for swimming pools. The system includes plastic panels mounted on the roof or fence facing south at an inclination of 30°. Water from the pool is circulated through the panels absorbing solar heat before returning to the pool.

Experiments will begin soon in the first house with solar cells on its roof which will provide for lights and appliances and for heating and cooling. Solar-cell-powered homes and office buildings may not be many years away.

The "heat pump" is a device that can both heat a house in the winter and cool it in the summer. In the winter, the heat pump takes heat from the air outside the house (even though the air may be freez-

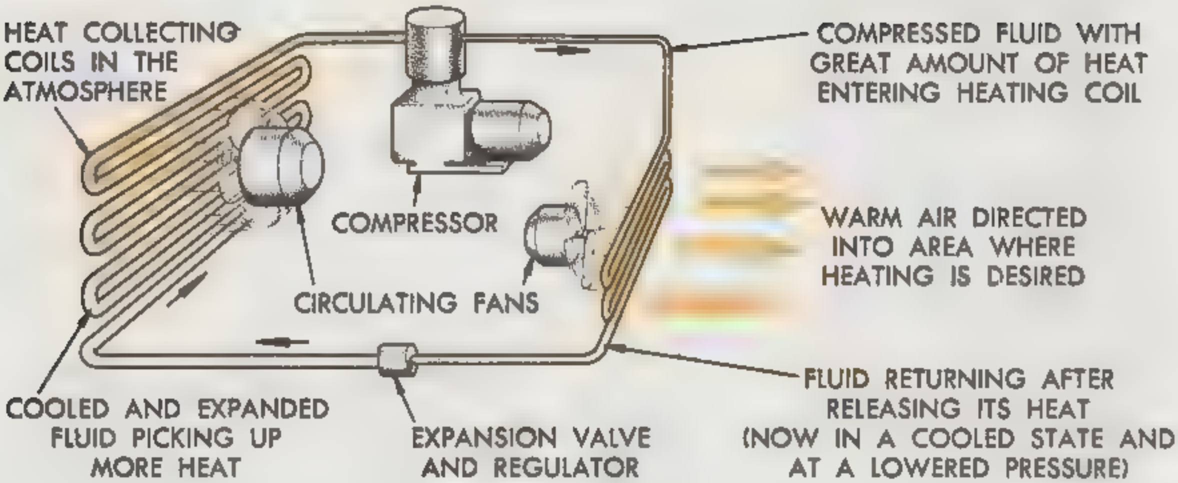
This dramatic photo of Skylab in space in June, 1973, shows the single solar wing forcibly extended by astronauts during a space walk. The light square is a parasol-like cover the crew improvised to reduce the temperature inside the craft. The four-bladed assembly is the solar panel which was not damaged during launch, but provided only part of needed power.

ing) and pumps the heat inside the house. In the summer, the heat pump works in reverse, taking heat from inside the house and pumping it outside. It then acts as an airconditioner. One day every house may have a heat pump, instead of a separate furnace and airconditioner.

The heat pump principle is easily explained. Your own refrigerator, for instance, extracts heat from the food you put into it and releases this heat into the kitchen. You don't ordinarily notice this heat released by your refrigerator because the kitchen is much larger than the refrigerator. But if the refrigerator were several times larger than the kitchen, the heat released by the refrigerator would keep the house warm in below-zero temperatures. Have you ever noticed the blast of warm air as you passed the outside of a window airconditioner? If that airconditioner were turned around in the window, the blast of warm air would be in the room. In this way, a heat pump can be used to cool *or* heat.

How can heat be obtained from the outside air when the temperature is below zero? In fact, there is heat in every substance, whether it is hot or cold to the touch. Its temperature tells us only the level of this

HOW A HEAT PUMP WORKS



Radiation from the sun is collected by the parabolic reflector and focused on a thermoelectric generator located just behind the "nose cone". Here a piece of wood bursts into flames. The heat, in fact, activates a thermoelectric device and powers an electric motor.

heat. For example, there is a tremendous amount of heat in the blanket of air surrounding the earth. But when this air is at a temperature of zero degrees F. it is too cold to heat a house or person. The heat pump takes this heat and raises it to a higher temperature, making it useful for heating houses.

Every refrigerator is a heat pump—it removes heat from the refrigerator box and pumps it into the room. To do this, an electric motor must perform a certain amount of mechanical work.

The electric motor is used to compress a gas, called a refrigerant. The gas becomes hot as it is compressed and is than cooled by outside air as it passes through a radiator at the back or bottom of the refrigerator. Then the cool high-pressure gas is allowed to expand through a nozzle into a series of coils inside the refrigerator. These coils are usually located around the freezer compartment. As the gas expands, it absorbs heat from inside the refrigerator, cooling it. The gas then returns to the compressor and the cycle is repeated.

The heat pump in the refrigerator causes heat to flow from a low-temperature region to a higher temperature region. As you've probably observed, this flow of heat never occurs spontaneously. Heat always flows from a warmer body to a cooler body. However, a heat pump can reverse the direction of this flow of heat, so that the warm body becomes even warmer, and the cool body becomes even cooler.

To reverse the natural flow of heat, work must be done. Energy must be used up to cause the heat flow from a lower temperature to a higher temperature. But strange as it may seem, a heat pump can take a small amount of mechanical or electrical energy and move several times as much heat energy from a cool body to a warm one.

A good oil or gas furnace runs at an efficiency of about 80 per cent. This means 80 per cent of the heat energy in the burning fuel is actually used to heat the house. Modern heat pumps run at a coefficient of performance of more than 2.0, that is, for every unit of energy supplied to the pump as electricity, more than two units of heat energy are transferred from one place to another. The extra energy comes from the heat in the outside air or in the ground.

The Magic of Microwave

MORE AND MORE we are hearing about a "new" form of heat for cooking foods in a fraction of the time it can be done in conventional

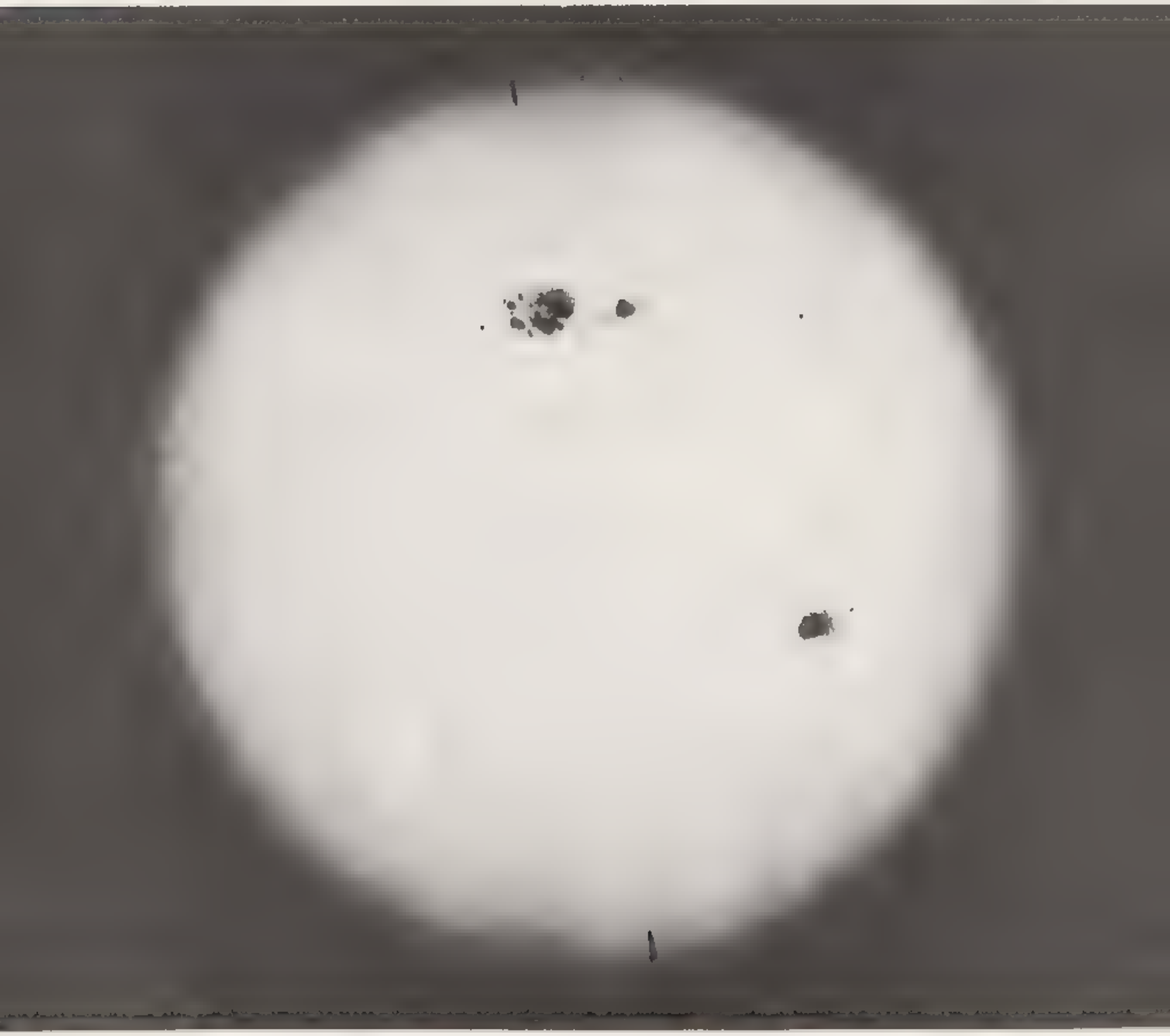
With the aid of microwave and infrared ovens, airline hostesses can prepare hot meals in a fraction of the time previously needed.

ovens. With the magic of *microwave energy,* you can bake a potato in two minutes, heat a roast beef sandwich in eight seconds, cook a lobster tail in one minute, or a trout in thirty seconds.

What is microwave heating all about?

The heart of the microwave oven is a magnetron tube. It doesn't directly produce heat—it produces energy in the form of a radio frequency signal which activates moisture molecules within the food. The moisture molecules oscillate at the rate of 2.5 billion times a second. This action makes them bump into each other, rubbing together and creating friction which, in turn, causes the food to heat rapidly. In conventional ovens the idea is to overwhelm the surface of the food with high temperatures, causing the food to cook slowly, one layer at a time.

When microwave ovens first were introduced, they were called revolutionary devices that could bring immediate magic into the kitchen. But initial costs have been fairly high, and by 1973 most of the 500,000 microwave ovens in service were found in institutions, cafeterias and aboard large airliners. However, by 1976, several million microwave ovens are expected to be in service and the prediction is that by 1980 they may be as common in the American home as the toaster is today.



This photograph of the sun, made by the Mt. Wilson Observatory, shows a group of sunspots. These are at a lower temperature than the sun's surface.

Plasma—the Fourth State of Matter

HAVE YOU EVER WONDERED how long it would be before the sun burns itself out? Although heat is being generated in the interior of the sun (and lost by radiation from its surface) at a rate equivalent to exploding 10 million million (10^{13}) hydrogen bombs per second, modern cosmologists expect the sun to be able to continue at this rate for about 5 to 10 billion years.

8. A PLASMA JET

The highest steady temperatures ever made by man are generated in a plasma. The temperature of the plasma shown here is in the region of 15,000° C. This picture was made with a filter—it was too bright for the naked eye.

The first clue to the mysterious processes within the sun was uncovered in 1930 by the great British astrophysicist, Sir Arthur E. Eddington. Sir Arthur showed that the sun is a mass of extremely hot, dense gas—so hot that its interior temperature is 15 to 30 million degrees centigrade.

This powerful rocket motor produces a temperature of about 3,000° C.—about the highest temperature possible with chemical fuels. The rocket produces 1.4 million pounds of thrust—equal to the horsepower of thirty-two Boeing 747 engines.

9. FUSION RESEARCH

This shows part of the laboratory equipment at General Electric where research is going on in the problems of mastering thermonuclear power by fusion. Temperatures of about 30 million degrees are achieved for very brief periods of time.

Fifteen million degrees C. is much too high a temperature to be the result of an ordinary chemical burning reaction—such as fuel burning in a rocket engine. Such chemical burning cannot create temperatures greater than about 6,000° C. The chemical bonds between the atoms simply do not have enough energy to generate higher temperatures.

Above 6,000° C. the violent random motion of the molecules causes them to break up into individual atoms. Even the most heat-resistant

materials, such as firebrick, turn into gases. At even higher temperatures, the collisions between atoms jar the electrons loose from their orbits. The gas then becomes a mixture of free electrons, positive ions, and neutral atoms. Such a state of matter is called a *plasma*.

In the sun's plasma the stripped atomic nuclei, travelling at very great speeds, occasionally crash into each other. Such a collision can produce thermonuclear fusion—the same nuclear process that takes place in the hydrogen bomb. In the sun, four hydrogen atomic nuclei are transformed into one helium atomic nucleus. This is how the sun creates the gigantic amounts of energy it continuously hurls into space.

The temperatures inside the stars seem fantastic when compared to more familiar temperatures on earth. And yet, ever since the hydrogen bomb was exploded, scientists have been fascinated with the possibility of creating such temperatures in the laboratory. They reasoned that if a little bit of the sun's plasma could be made and controlled in the laboratory, man would have an almost inexhaustible source of energy. To achieve this, scientists began to study the state of matter at very high temperatures.

The exhaust of a rocket motor has a temperature of about 3,000° C. —just about the highest temperature that can be achieved with chemical fuels. Higher temperatures can be found only in plasmas, where chemical bonds between atoms no longer exist.

One of the simplest methods of making a hot plasma is to use a shock tube. This device creates the same kind of shock wave that a supersonic plane makes. A typical shock tube may be between ten and fifty feet long, often separated into two parts by a metal diaphragm. On one side of the diaphragm the tube contains hydrogen, and on the other side the tube is filled with some inert gas, such as argon. When hydrogen is mixed with oxygen and exploded, the diaphragm bursts. The shock wave resulting from the explosion travels down the argon-filled part of the tube. The argon gas in the shock wave is so highly compressed that it becomes extremely hot. When this shock wave hits anything in the tube, such as a model of a space capsule nose cone, it is compressed still further, to even higher temperatures. A shock wave travelling at the

(*Following pages*) A rod of tungsten steel is subjected to the incredible heat of a plasma jet in order that its rate of ablation may be studied.

speed of Mach 20 (twenty times the speed of sound) will heat air to about 6,000° C.—which is roughly the temperature of the sun's surface.

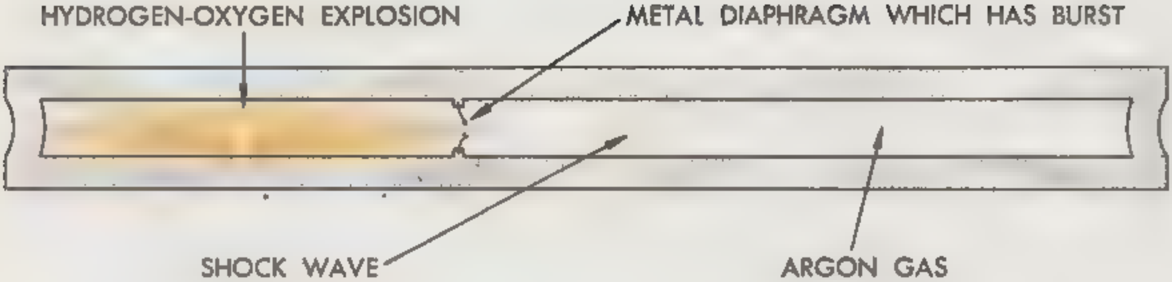
A shock tube is useful in research, but it can provide only single bursts of high-temperature gas. The first continuous high-temperature flame, created only a decade or so ago, is generated by a device called a plasma jet. It produces a jet of hot ionized gases at temperatures higher than 15,000° C.—more than twice the temperature of the sun's surface, and five times hotter than a rocket motor's exhaust. The plasma jet generates the highest *steady* temperatures ever made by man.

The plasma jet is a special type of electric arc. It has a built-in cooling system which pipes water through the electrodes so that they

10. STATIC ROCKET TEST

More than one million pounds of thrust streams from an F-1 rocket engine undergoing static tests in California.

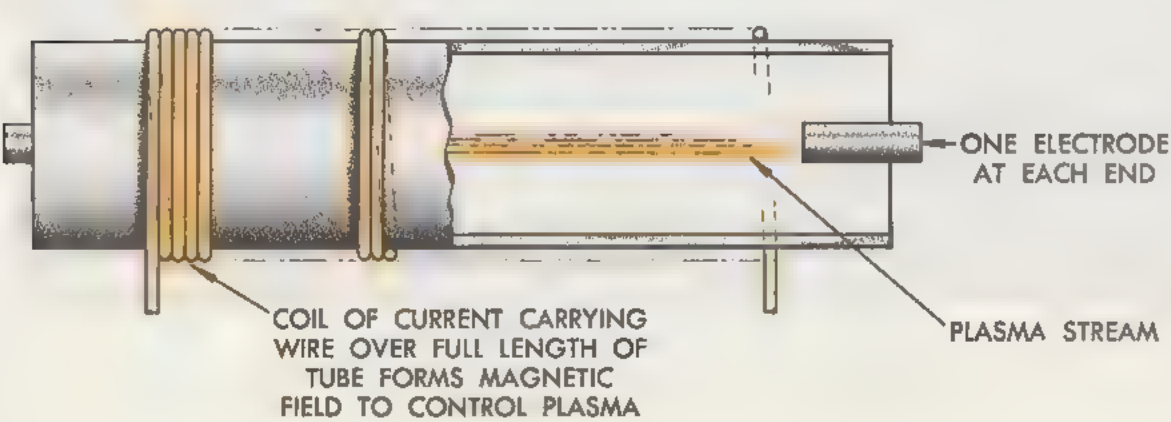
SIMPLIFIED SHOCK TUBE

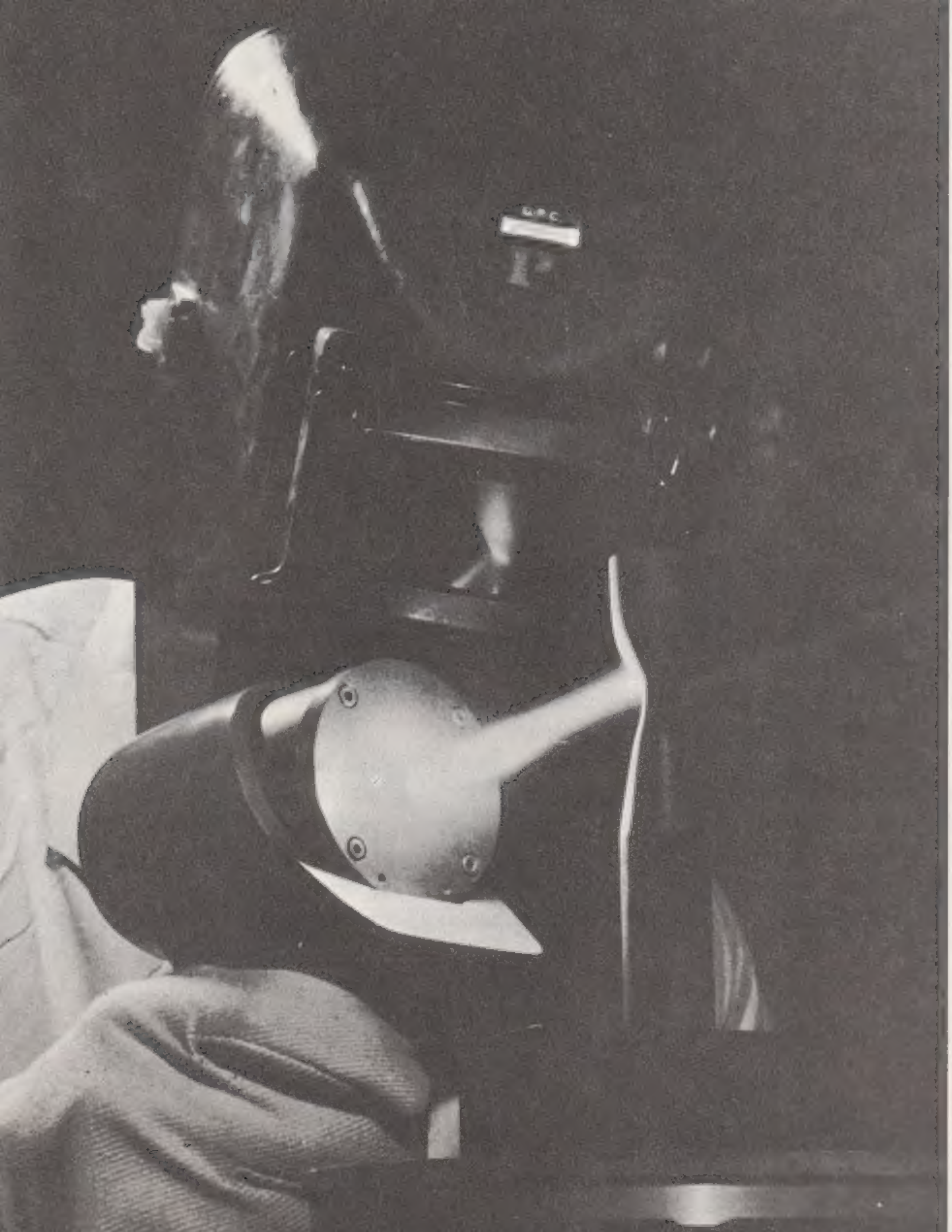


won't vaporize at the ultra-high temperatures. When the switch is thrown and the arc is struck, a stream of positive ions and electrons flows between the two electrodes. The thin stream of charged particles in the hot gas acts as an electric current. The ions and the electrons flow in a tight, thin bundle, and shoot out as a foot-long jet of hot plasma, too brilliant to look at with the naked eye.

Scientists hope one day to create a hydrogen plasma at *sustained* temperatures of millions of degrees—the same temperature that exists in the interior of the sun and stars. Such an achievement would be like capturing a bit of the sun's interior within a bottle. To achieve this goal, scientists in many countries have been trying to make a "magnetic bottle"—the most likely container for the high-temperature plasma.

SIMPLIFIED "MAGNETIC BOTTLE"





Wearing a protective helmet and dark-glass eye-shield, a technician forms a free-standing nozzle shape with blasts of heat from a plasma spray gun.

One form of this magnetic bottle is a simple tube with an electrode at each end and surrounded by a coil of wire. The plasma flows down the length of the tube from one electrode to the other. The coil of wire around the tube generates a magnetic field which squeezes the plasma into a tight, thin stream. This raises the temperature and pressure within the plasma even further. The magnetic field also keeps the plasma, in the central portion of the tube, away from the walls which would cool it. By pushing more current through plasmas for higher temperatures, and squeezing the gas still further with stronger magnetic fields, researchers hope to create controlled thermonuclear fusion.

Fusion experiments are now in progress in laboratories throughout the world. Perhaps in twenty, thirty, or fifty years sustained temperatures of hundreds of millions of degrees will be achieved within a magnetic bottle. At that time, man will have made his own sun on earth.

Inventions in Which Heat Played a Role

Date	*Invention*	*Inventor*	*Country*
1698	Steam pump	Thomas Savery	England
1712	Steam engine	Thomas Newcomen	England
1765	Condensing steam engine	James Watt	Scotland
1769	Steam-driven tractor	N. Joseph Cugnot	France
1783	Gas balloon	J. E. & E. M. Montgolfier	France
1784	Puddling iron furnace	Henry Cort	England
1786	Power loom	Edmund Cartwright	England
1786	Threshing machine	Andrew Meikle	Scotland
1790	Steamboat	John Fitch	America
1804	Steam locomotive	Richard Trevithick	England
1807	Commercially successful steamboat	Robert Fulton	America
1811	Steam-powered printing press	Friedrich Koenig	Germany

1825	Commercially successful steam locomotive	George Stephenson	England
1835	Steam shovel	William S. Otis	America
1839	Steam hammer	James Nasmyth	Scotland
1849	Francis turbine	James B. Francis	America
1857	Open-hearth steel-making furnace	Frederick & William Siemens	England
1860	Internal combustion engine	Etienne Lenoir	France
1876	Four-cycle gas engine (Otto engine)	Nikolaus August Otto Eugen Langen	Germany
1884	Linotype machine	Ottmar Mergenthaler	Germany-U.S.
1884	Steam turbine	Sir Charles A. Parsons	England
1885	Automobile	Karl Benz	Germany
1887	Monotype machine	Talbert Langston	America
1892	Diesel engine	Rudolf Diesel	Germany
1903	Airplane	Orville & Wilbur Wright	America
1911	Air conditioning	Willis H. Carrier	America
1913	Refrigerator	A. H. Goss	America
1918	Automatic toaster	Charles Strite	America
1924	Diesel electric locomotive	Hermann Lemp	America
1926	Liquid-fuel rocket	Dr. Robert H. Goddard	America
1930	Jet-propulsion engine	Frank Whittle	England
1939	Helicopter	Igor Sikorsky	America
1942	Nuclear reactor	Enrico Fermi	Italy-U.S.
1954	Solar battery	Gerald L. Pearson Calvin S. Fuller Daryl M. Chapin	America
1957	Thermionic (heat to electricity) converter	Dr. Volney C. Wilson	America
1963	Commercial gas-turbine automobile	George Heubner, Jr., and team	America

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